COMMUNICATIONS DEVELOPMENT TRAINING

FUNDAMENTALS OF SWITCHING



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COMMUNICATIONS DEVELOPMENT
TRAINING

FUNDAMENTALS OF SWITCHING

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INSTRUCTOR-IN-CHARGE

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PREFACE

Switching is basic to telephone communication. It is the art of establishing a voice channel between telephones—no matter where they are located—to enable people to talk to each other as they wish. The number of such channels that are established daily by the Bell System at present averages approximately 160 millions.

In the Bell Laboratories many engineers are devoting their efforts entirely to the design of switching systems. In the past the technique of design was acquired primarily by working at it. During the last few years a program was inaugurated for training young engineers in this field. Preliminary notes were prepared for that purpose and the present text is based on those notes.

In organizing, writing, and teaching a course on switching, three fundamental factors must be taken into consideration.

First, the fact must be faced that present college courses do not include the subject. This necessitates starting with the most elementary concepts, principles, techniques, and instrumentalities.

Second, the subject is large and complex, posing the problems of interconnecting automatically and swiftly any two telephones amongst the many millions spread over a continent and beyond. Because of the limited time available for training, an all-inclusive treatment of the subject is, therefore, not practicable.

The third factor relates to the nature of switching. In spite of past and present effort, it has not yet been made into a formal science to any material extent. It remains primarily the creative art of engineer-craftsmen. This means that it cannot be presented in terms of formulas, derivations, proofs, and so forth.

The complete switching text for the Communication Development Training program is planned in four volumes, corresponding to the four semesters of the program. This first volume—Fundamentals of Switching—consists of two distinct parts. Chapters 1 to 12 present in general terms the scope, nature, and variety of switching problems. Beyond Chapter 12 there is an abrupt change in the type of material, and the remaining nine chapters discuss elementary switching circuit design techniques. The text is far from perfect. We are still in the stage of creating symbols, defining terms, distilling concepts, and so forth.

With the exception of Chapter 8, this volume was prepared by Messrs. G. R. Frost, W. S. Hayward, W. Keister, A. E. Ritchie and S. H. Washburn. The writer helped as a coordinator and as a hard-to-please critic. Chapter 8 was contributed by Mr. A. E. Joel.

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It is appropriate here to express appreciation to the Program Committee of the Communication Development Training for lively and instructive discussions of how switching should be taught. In addition, Mr. M. Sultzer of this committee read the full text and gave constructive suggestions to improve the presentation.

The final thought in this Preface is a tribute to the hundreds of switching engineers of the Laboratories, and their supervisors, who—through hard work, ingenuity and inventiveness—have created and brought to fullness over the years the switching art of the Bell System.

J. MESZAR
BELL TELEPHONE LABORATORIES, INC.
November, 1948

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CHAPTER 1

PREVIEW OF TELEPHONE SWITCHING

1.1 GENERAL

This course is concerned with telephone switching. A telephone subscriber expects to be able at any time to converse with any other one of a large number of subscribers. Telephone switching is the means by which a communication channel between any two subscribers is established and maintained during the conversation. The transmission characteristics of the established communication channel are usually of little concern in switching. In this course they will seldom be mentioned except in those few cases where the nature of the transmission path or the requirements necessary to maintain a satisfactory grade of transmission directly influence switching procedures.

The usual college or university engineering training gives no intimation of the nature or size of the problems encountered in telephone switching. A conventional communication course is concerned primarily with transmission subjects such as frequency response, bandwidth, attenuation, amplification, modulation, carrier transmission, and radio links. Switching is seldom, if ever, mentioned. Yet most of our everyday telephone conversations take place over the simplest elementary type of telephone transmission path which is a pair of wires. In contrast, the mechanisms in the larger cities which select and establish these simple transmission paths, one to each single subscriber desired among millions, are integrated together into what is unquestionably the largest and most complex machine in existence.

A comprehensive picture of telephone switching is difficult to present. It consists of a great many intricate details combined into an over-all system which operates along certain broad principles. As an example of the magnitude of these details, one of our modern automatic switching systems contains several master control circuits each consisting of some 1500 relays. One of these circuits is able to select particular circuit paths and establish a desired connection in less than one second. In doing this some 700 relays operate and 10,000 or so electrical contacts are closed and opened. This is quite different from any simple idea of telephone switching which one may have obtained from observation of a one-operator manual switchboard in some hotel lobby, but is more typical of what takes place in an actual automatic switching system. First intimate acquaintance with such a switching system gives the impression that there is nothing but detail, and the

sheer mental effort required to follow through the sequence of some intricate series of actions is often discouraging.

Paradoxically, actual details are frequently unimportant, but the nature of a switching system is such that it cannot be appreciated without the ability to evaluate and understand details. This is because almost any problem in switching has a number of solutions, all good and yet all differing completely in detail. Also many of the details of a switching system are not concerned with basic and fundamental switching requirements but have to do with auxiliary features found necessary to give efficient and economic service, or to satisfy the desires of subscribers in a practical system. Details of execution of such auxiliary features again are unimportant, but must be considered in evaluating a system plan. In other words during the design or analysis of switching systems, recognition of the nature of problems, and the fact that reasonable solutions are possible, is of more fundamental importance than a complete knowledge of the detailed operations of particular circuits.

This text on fundamentals of switching presents the broad as well as the detailed view of switching. The remainder of this chapter outlines in a very general way the nature of switching systems and the problems encountered. The immediately following chapters discuss the broad principles of telephone switching systems and the nature of some of the detailed problems. Our chief concern is with automatic or dial systems, although examples from manual systems employing operators will be used on occasion for illustrative purposes. No particular system will be described specifically but basic principles applicable to all will be discussed. The emphasis is on present-day techniques with occasional glances toward the future.

The later chapters of the text, beginning with Chapter 13, deal with detailed design techniques used in solving specific switching problems. The subject is developed to bring out design principles rather than describe existing circuits. Details are discussed, down to individual relays and contact springs, but the treatment is abstract and applies to the design of switching circuits for any purpose. A final chapter discusses the use of electronic devices in switching and control circuits.

1.2 THE BASIC NATURE OF SWITCHING PROBLEMS

Telephone switching problems are more logical than electrical, and the design of switching circuits is primarily an exercise in rigorous logic. This is probably a surprise to one who is aware of telephone switching as a phase of telephone communications, and who has some familiarity with transmission problems and the use of electronics in the general communications field. In switching design the problem is usually one of producing logical effects in response to certain causes. Electrical apparatus is merely a convenient means of bringing about desired effects.

At this stage, the above viewpoint on switching has to be accepted simply as a statement. Its validity will become obvious only as a result of substantial exposure to specific switching problems and their solutions.

1.3 SCOPE OF SWITCHING

The geographical distribution of Bell System telephone subscribers results in thick clustering about centers of population, and on the other hand there are large areas with only a scattered few subscribers. There are about 30,000,000 of these subscribers and any one of them may have to be connected to any other one as the occasion demands. This ability of one subscriber to reach any other subscriber is a fundamental requirement of the telephone systems. This is accomplished by means of switching centers strategically located to serve the telephone users. These centers are connected together and to the subscribers in a vast interconnecting network of communication paths which employs over 100,000,000 miles of wire in underground and aerial cable and open-wire lines.

Telephone calls between subscribers are known as telephone traffic and it is necessary that the system be able to handle the required volume of traffic in a reasonable manner. This means not only that the interconnecting network must provide a way for any subscriber to reach any other, but also that the number of circuit paths in branches of the network, and the facilities provided in the switching centers, must be adequate to handle the flow of calls without traffic jams. The total traffic in the Bell System averages more than 160,000,000 calls each day. Most of these calls are between subscribers in the same locality, but about 6,000,000 are between population centers.

Consider the distribution of traffic in relation to the telephone population. Within the centers of population there will be a large number of local calls between subscribers. There is said to be high "community of interest" among these subscribers and a proportionately large local traffic. The population centers vary considerably in character. In some cases the size and population density is such that it is practical to place all the switching apparatus in one central location. There are other places where the population is scattered in a semirural area and long transmission circuits are required to reach the various subscribers. Switching apparatus is often placed at several points in these localities. Often in these cases several quite small switching centers are associated for special services and administrative purposes with a larger center located in the largest town in the area.

There are some regions where a dense population extends over a relatively large area and both the length of individual connections as well as the large volume of simultaneous connections are problems. The metropolitan New York area is an example where over 3,000,000 subscribers may make as many as 30,000,000 calls on the busiest days.

The traffic between population centers is known as long distance or toll traffic. The amount of this traffic will vary with the size of the population centers and the distance between them. In many cases throughout the country the population centers are at considerable distances from each other and the toll calls to points outside of the community are relatively few compared to the local calls. However, around the population centers of large cities there are frequently suburban

towns which have a substantial local community of interest but also have interests in the city with corresponding volume of telephone traffic to the city. This type of short-haul toll traffic in some cases is quite large and presents some problems which are quite different from local traffic.

The means of organizing telephone traffic and giving subscribers rapid and economical service is provided by switching centers which contain the switching equipment to serve a given area or group of subscribers and which are placed in central locations. The switching center is essentially an aggregate of electro-mechanical apparatus which establishes transmission paths as required. Connections may be controlled automatically in response to signals received, or may be manually controlled by an operator according to verbal instructions. Each subscriber is connected to a switching center by means of a subscriber's line, and the switching centers themselves are interconnected by means of trunks. A switching center may connect a subscriber's line directly to another subscriber's line, or connect through trunks to other centers to reach the desired line. Thus any desired connection can be built up by linking together appropriate trunks. Transmission characteristics of individual links determine the maximum number of links in any single connection. The nature of this network is indicated by Figure 1-1 which shows the

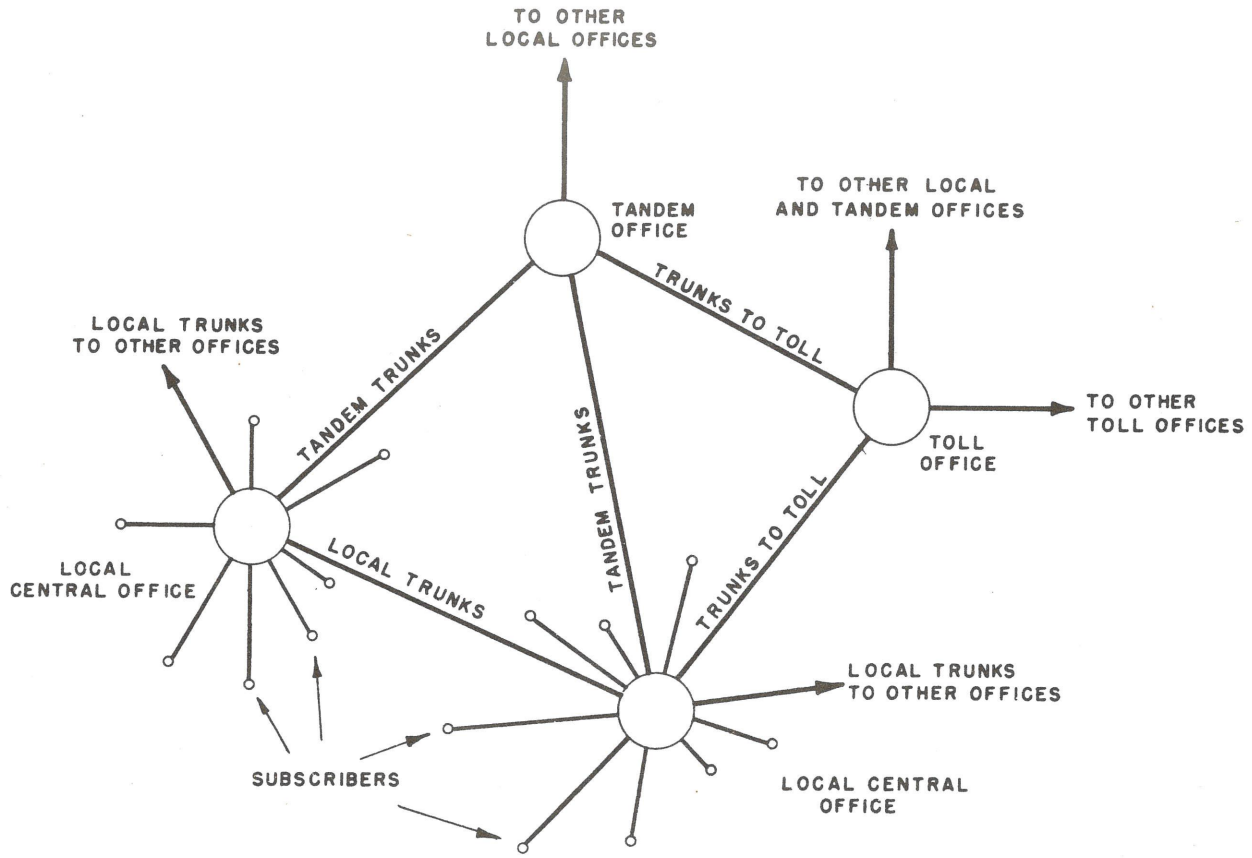


Figure 1-1 Interconnection of Subscribers and Switching Centers

interconnection of various types of switching centers and trunks described in the following paragraphs.

Central Offices

The switching center directly serving subscribers' lines is known as a local central office. Central offices are usually located at some point near the geographical center of a group of subscribers so that the lengths of subscribers' lines can be kept at a minimum. The size of the central office will depend on the number of subscribers, and from as few as a dozen up to a maximum of 10,000 subscribers may be served by one office. This top limit is solely the outcome of a number of arbitrary but practical factors which will be made evident in later chapters. The term local central office as generally used refers to the actual switching machine serving a group of subscribers and should not be thought of as the central office building housing the switching apparatus. In order to reduce the length of subscriber lines, several central office buildings may be located in an area and, when the concentration of subscribers is great, several central offices may be located in one building. Central offices, whether located in the same or different buildings, are connected together by local trunks.

Equipment located outside of telephone buildings, such as subscriber lines and trunks between offices, is known as outside plant. The location and planning of telephone buildings and equipment for a local area is a problem of economic balance between the cost of outside plant and the expense of providing and maintaining buildings and equipment at several locations. An attempt is made to locate a central office building so that the subscribers served have a high community of interest and transact most of their telephone business with other subscribers served from the same building. The number of outside trunks to other offices is thus kept at a minimum. In large metropolitan areas, communities of interest are widespread and a large percentage of all calls require the use of trunks between offices.

The 10,000-line limit is a convenient switching machine capacity limit. In densely populated areas where subscriber concentration is great, several 10,000-line capacity switching systems may be located in a single building. These switching systems function independently with some sharing of common equipment and are designated as separate offices. Trunks are provided between two such offices but these are simple wiring connections within the building.

Tandem Offices

In an ordinary local call between subscribers in different central offices, the connection is established over a trunk between the two offices. The number of trunks in a group connecting two offices is determined by the expected traffic between them. Where the number of offices in an area is large there may be many offices to which a particular office has little traffic. The resulting network of trunks between offices will contain many small groups of trunks, and, as will be shown in a later chapter, small groups of trunks are uneconomical in the use of

outside plant and switching equipment. A more efficient method is to provide an intermediate switching center between central offices which is called a tandem office. The tandem office serves central offices, in much the same way as the central office serves individual subscribers. Each central office has trunks to the tandem office where connections to other central offices may be established. These are called tandem trunks.

The trunking network for local calls in a large population center consists of direct trunks between offices as well as trunks to tandem offices. Each central office has direct trunks to those offices to which it has considerable traffic, and in addition has trunks to the tandem offices. Traffic to offices which is not heavy enough to justify direct trunks is switched through a tandem office. The tandem trunks may also be used between two offices having direct trunks when these trunks are overloaded during heavy traffic. When trunks through tandem are used as an alternate choice they are known as an alternate route, while the direct trunks are a direct route. In very large metropolitan areas several tandem offices may be provided, each of which has trunks to certain central offices as well as to the other tandem offices. Each central office may have trunks to two or more tandem offices but each tandem office does not necessarily have trunks to every central office.

Toll Offices

Telephone calls between population centers are switched through offices known as toll offices. These calls are the "long distance" calls which are billed individually to the subscriber according to distance and conversation time, and hence are known as toll calls. The transmission problems in long distance toll circuits are quite different from those in local circuits. This difference is reflected in the somewhat different techniques used in switching toll circuits. Basically, however, the toll office performs a switching function similar to that of central offices in switching incoming circuits to outgoing circuits.

A toll office will have trunks to local tandem offices and also direct trunks to nearby local central offices. It will also have intertoll trunks to toll offices in other localities. All toll offices are part of a nationwide intertoll trunking network through which any locality can be reached by switching from one toll office to another. This nationwide network is integrated into a comprehensive switching plan in order that intertoll trunks may be efficiently used, connections established quickly, and that the total number of links in any connection shall not be too large for satisfactory transmission.

1.4 THE MAJOR PROBLEMS OF SWITCHING

We have seen that telephone subscribers are served by a network of subscribers' lines, local, tandem, and intertoll trunks which are connected together in various switching centers to furnish a subscriber-to-subscriber transmission path. Let us now examine more closely the actions which must take place within one of these switching centers, such as a local central office. The end terminals

of subscribers' lines and trunks appear in this office and the basic problem becomes one of connecting these terminals together in pairs as required for each telephone conversation. There are three fundamental aspects of this problem, namely: (1) the type of switching apparatus provided for making connections, (2) the interconnecting network of paths within the office by which any line or trunk may be connected to any other desired line or trunk, and (3) the control means by which the switching apparatus is caused to connect together the proper paths for a particular conversation.

These three are closely interrelated, the nature of each depending to a great extent but not completely on the characteristics of the others. A brief discussion of each will indicate the types of problems encountered in switching. Later chapters will indicate how these are solved.

The Apparatus

A simple and obvious way of making telephone connections would be to provide a supply of wire lengths and use them to connect the terminals of calling and called lines together as required. In fact, in the very early days of the telephone this was done. This was a simple and direct method of accomplishing the desired results but has obvious disadvantages. An improvement was to substitute jacks for the terminals to which lines are connected and provide cords equipped with plugs on each end in place of the wire lengths. This is basically what is done in present-day manual switchboards. Trunks and lines are connected to jacks in front of an operator who has a number of double-ended cords by means of which connections between these lines and trunks can be made.

A manual switchboard with its jacks and plugs has much to recommend it as a switching device. An array of 10,000 jacks can be placed within the reach of a single operator. This operator may insert the plug of a connecting cord into any one of the 10,000 jacks. Having inserted a plug in one of the jacks, a second connection may be made in the same array of jacks by means of a second plug, and so on. Due to the flexibility of the cords and the control by operators, each connection makes only its own plugs and jacks busy and does not block access to other jacks in the same array.

The plugs and jacks of a manual switchboard establish connections in a direct and obvious manner but are not easily adaptable to automatic control. Automatic switching systems require switching devices which also must be able to make a connection from one point to any one of a number of other points. In practically all present-day automatic switching systems these connections are made by mechanical motions of metallic contact elements.

One class of mechanical switching devices has a single contact (or brush) which can be moved to connect to any one of an array of contact terminals ("travelling switch"). A familiar example is an ordinary rotary switch with its arc of contact points. Several are usually ganged together physically to provide the necessary number of electrical paths for a communication channel. Such switches are made in a variety of forms. Some employ rotary motion, while in others the

contacts are arranged in a straight line with the brushes carried by sliding rods. Still others employ two mechanical motions, such as vertical and rotary, with a field of contacts consisting of a number of arcs stacked one above the other (Figure 1-2). Many of these are driven by electromagnetically operated ratchets, while others are driven by clutches on continuously rotating shafts.

In mechanical switches each brush has its own array of bank terminals and only one connection can be established within this set of terminals at any one time. A second connection must employ a second brush with its own bank of contacts. This is characteristic of all practical mechanical switches and was not true in the manual switchboard. We see then that a particular switch makes very inefficient use of its output terminals, using only one of them at a time. This efficiency decreases as switch access increases; for example, a 10-point switch uses 10 per cent of its output access while a 100-point switch uses only 1 per cent for any given connection. This is one of the important factors which must be evaluated in telephone switching systems. Other characteristics of large access switches may help to offset their low output terminal efficiency.

Another type of switch is a "small motion" switch. In these switches a connection is made through mating pairs of contact elements of the type used on electromagnetic relays. An input is connected to a number of contact elements, each of which mates with a corresponding element associated with an output. A connection is made by closing a selected pair of contact elements. The crossbar switch is the most common switch of this type and is widely used in switching systems (See Figure 1-3). In some small "all relay" systems groups of individual relays are used as connecting devices. The problems of control of this type switch are quite different from those of the moving brush-type switch. Moving brush-type switches are capable of some degree of self-control, while the relay-like switches depend entirely on external control means to determine which contacts shall be closed.

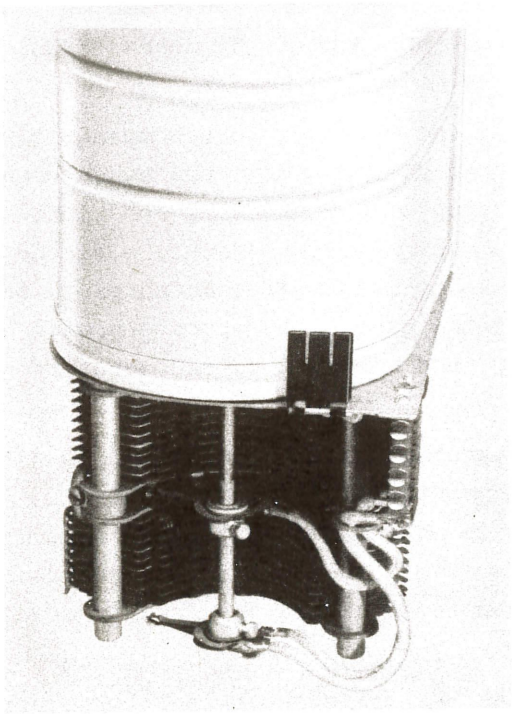


Figure 1-2 Ganged Brush and Bank Terminals of a Step-by-Step Type Switch Which Makes Connections by a Combination of Vertical and Rotary Motions of the Brushes

Problems of practical mechanical design determine to a great extent the characteristics of mechanical switches. These characteristics in turn influence greatly the ways in which these switches may be used in

switching systems. Often the basic plan of a switching system, both interconnections and control, is built around the characteristics of the switch. In other cases a particular type of switch is chosen (or even specifically designed) to fit into some plan of interconnection or control.

One of the basic characteristics of mechanical switches influencing system design is the limitation of access. The access of a switch is the number of points to which it can directly connect its input. In the example of the manual switchboard the plug has access to 10,000 jacks. Mechanical switches have much less access capacity. In practical types of switches the contact array appearing before a given brush may contain from 10 to 500 outputs. Since a subscriber may require a connection to one of several thousand lines or trunks in the office, it is evident that schemes must be devised to use several switches to establish a single connection. This complicates the interconnections and control. In fact, in modern automatic systems the interconnections of small-access switches and their control to provide the required large access often accounts for a great share of the complexity of the system.

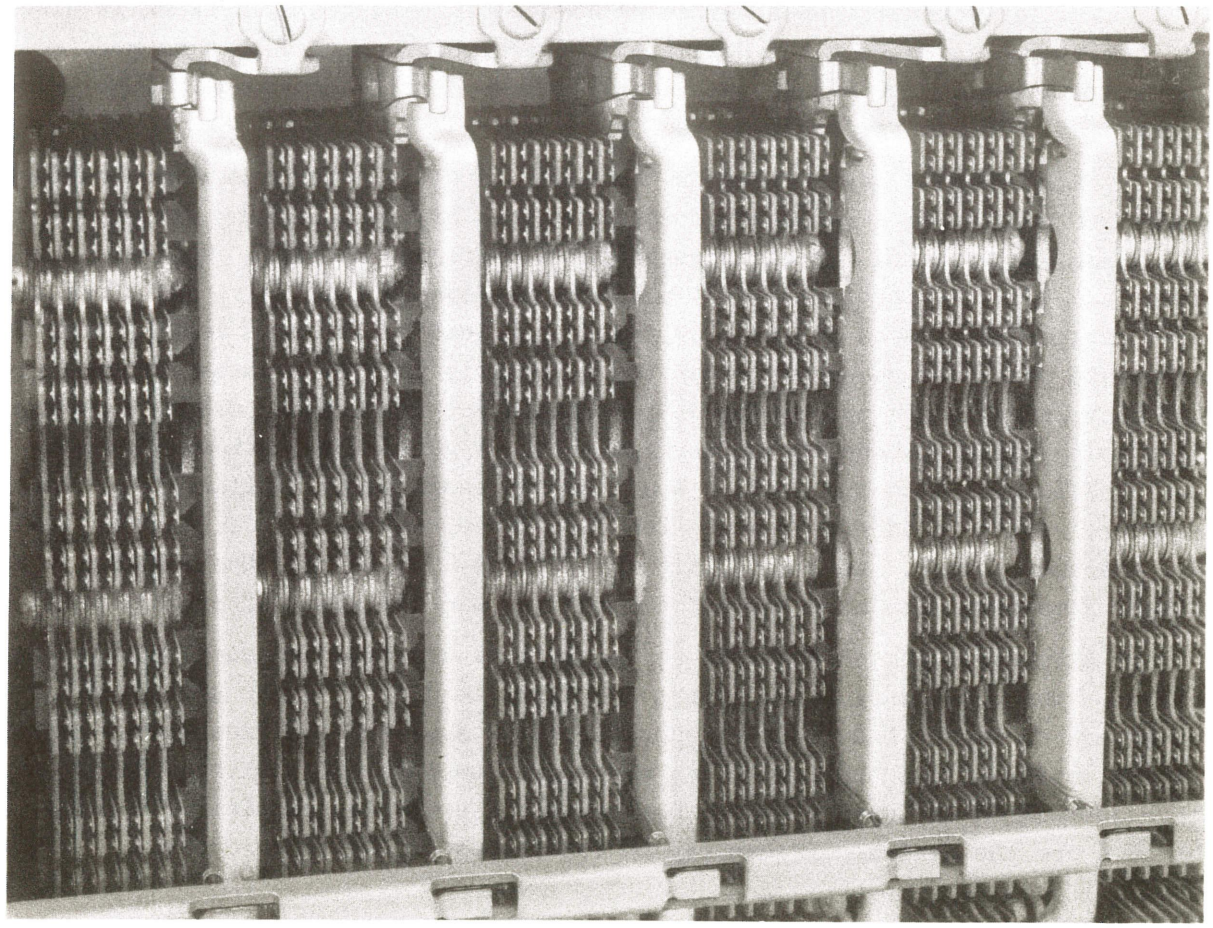


Figure 1-3 A Portion of a Crossbar Switch
Showing the Many Relay-Like Contacts

The Interconnecting Network

The crude interconnection system mentioned in the previous section, using wire lengths between line and trunk terminals, is an example of a very simple interconnecting network within a switching center. At present, however, practical switching devices suitable for automatic control cannot take advantage of the simplicity of such an interconnecting network because of their relatively small access. This limitation is overcome by combining a number of switching devices into an interconnecting network which provides the necessary access. Such an interconnecting network consists of numerous "links" or sections of talking paths, the ends of which are joined to other links by means of the switching devices to provide a complete talking circuit for any telephone conversation.

The patterns in which these interconnecting links are arranged follow some well-ordered plan. This is necessary for efficient use and to permit suitable links for a particular connection to be quickly and accurately selected. There are a number of basic plans for these interconnection patterns, and quantitative variations within each pattern allow for particular conditions and amounts of traffic.

The interconnection of switching devices in a switching network is discussed at some length in Chapter 4. However, a general picture of such a network will be developed a little further at this point because of its importance in the over-all picture of telephone switching.

If we imagine any subscriber "looking" into the interconnecting network, he would see before him a repeatedly branching tree of links leading ultimately to all other subscribers. At each branch point there are multiple choices. Some of them lead toward a particular destination while others lead away, and there are alternative paths which directly or indirectly lead to the same destination. These alternate paths are necessary since the network is used by a number of subscribers, and busy links in use by one subscriber should not block other subscribers from completing calls through the network in the same general direction. Two subscribers looking into the network would see an essentially similar view. These, however, cannot be identical since the two subscribers must at least have individual entrance points. As a connection progresses further into the network it finds itself competing with more subscribers for the use of groups of circuit paths.

Only a portion of the over-all network is contained in any one switching office. The various types of trunks are links leading to other switching offices where access may be had to other subscribers or trunks. The first-order problem is the design of a switching office which can complete calls within itself. The interconnection of these offices then becomes a switching problem of a higher order where the central offices may be considered as switching devices.

The Control

Having developed an idea of the nature of an interconnecting network, let us now consider the control of these networks in establishing telephone

conversation paths. A more extensive discussion of control principles and techniques is given in Chapters 3 and 5. At present we will discuss in a very general manner only the type of problems encountered.

A connection through an interconnecting network requires the setting of a number of switching devices in order to build up a satisfactory path by joining sections or links together. This means that the control mechanism must both determine which switch connections are to be made and cause the switching devices to act to make these connections. The actual setting of the switching devices is fundamentally simple, although in some mechanical switches it may employ ingenious arrangements of electromagnets, ratchets, and levers. By far the more difficult problem is that of determining which switches to set and the positions to set them in. In some systems this is closely related to the setting of the switches but in others it is entirely separate. Control mechanisms in many large switching systems determine in advance which connections are to be closed to establish a transmission path before any of the switches are caused to act.

A path through a switching network involves two sorts of connecting actions: (1) selecting from among paths leading in all directions those paths which lead in the desired direction, and (2) choosing a particular path from a group of idle paths which are essentially similar and lead in the same direction. The first action is in accordance with the desire of the calling subscriber to reach a particular destination. The second action is performed by the control means according to some plan after examining the busy and idle conditions of paths in the chosen group. These two actions are often closely intermingled, but a practical network will provide several ways to reach a given destination, any one of which is equally satisfactory to the subscriber.

A calling subscriber desires a connection, not to any subscriber, but to a particular one of the thousands or millions which may be reached through the network. Individual subscribers are identified by the familiar "telephone numbers" listed in the telephone directory and known as directory numbers. When originating a call a subscriber will transmit to the switching office the directory number of the desired subscriber. Since this is the only direct instruction received by the central office, the control system must determine from it which groups of circuit paths may be used.

In some types of switching systems the digits of the directory number themselves are instructions for setting the switches and identify the groups of links which may be used in establishing the connection. A call through a system of this kind proceeds from point to point. At each point the interconnecting network and the control are so arranged that some portion of the directory number indicates the direction in which to proceed. In these systems the called subscriber lines are located on terminals of the switching network in a definite order corresponding to their directory numbers. Lines having consecutive numbers appear on adjacent switch terminals.

In switching systems of somewhat higher order of complexity, the directory numbers are purely arbitrary so far as the switching network layout is concerned

and serve only to identify the subscribers. These systems provide a cross-reference device which, upon being presented with the called subscribers directory number, will return information which indicates the procedures to follow in connecting to this subscriber's line. This obviously complicates control problems but permits considerable flexibility in the assignment of directory numbers and switch locations. The full advantages will be appreciated only after the discussions of later chapters, but one important example will be given here.

Due to chance and circumstances such as business expansion, and the like, the telephone traffic of a group of subscribers served by a group of switching paths may increase so as to overload these paths while the paths to some other group of subscribers remain relatively light-loaded. A remedy would be to interchange the switch locations of the lines of some of the heavy-traffic subscribers with those in the light-traffic group so as to equalize the loads on the switching paths. When the directory number identifies switch location this cannot be done without also changing directory numbers. There are obvious objections to this. With the cross-reference system the subscribers may be assigned switch locations without regard to directory numbers in order to equalize traffic throughout the switching network.

In some switching systems the actual control devices are associated with individual switches or small groups of switches. This control is not very complex and may consist of moving a switch brush to a particular position according to instructions, examining the individual circuits of a group in this position, and connecting to one which is idle.

The picture is quite different in some of our larger so-called "Common Control" switching systems. Here most of the control is concentrated in master control units which are called "markers" and consist mostly of relays. These markers are able to reach out into a large interconnecting network serving thousands of subscribers and by means of an extensive system of test and control leads determine the busy and idle condition of any link in the network and set the switching devices to the required positions. Figure 1-4 is a photograph taken during the installation of a No. 5 Crossbar System and gives an idea of the complexity of a modern switching system. A marker will be installed in the space in the foreground. The hanging coils of cables are a part of the many leads which will be connected to the marker as a means of transmitting and receiving information and controlling the action of switching elements. The units visible beyond and beside the marker are registers. The actions of these markers are truly remarkable. Merely mentioning some typical actions will give an idea of the problems of a large automatic switching system. It is our purpose to develop these more fully in later chapters.

The markers do not deal directly with subscribers. The system contains a number of smaller* control units called "registers" which act as agents between

*About 200 relays. A marker may contain as many as 1500 relays.

originating subscribers and markers. The register receives as instructions the directory number of the called subscriber, remembers it, and transmits it in a more efficient manner to a marker. Having previously learned the calling subscriber's line location at the time it was originally connected to the subscriber's line, the register also tells this to the marker. The marker examines the information and determines whether the call is outgoing to some other office or can be locally completed within the office. It knows the location of the various trunk groups and can examine the group serving a particular destination and choose one trunk which is idle. When a connection to a terminating line in its own office is involved, the marker consults the cross-reference device to learn where that line is located. As a result of these actions the marker knows the terminal locations (on the boundaries of the interconnecting network) of the lines or trunks which must be connected together through the network. It has been mentioned that interconnecting networks provide several ways of making any given connection. The marker connects to and tests groups of links which can be connected together to form a number of independent paths through the network. From these a suitable set of idle links is selected.

This is a bare outline of typical control actions in a large switching system. A marker must often modify its actions according to situations encountered while attempting to set up a connection. If the called line is busy it connects the calling line to a source of tone to return a busy signal to the calling subscriber. If all the trunks of a group are busy the marker usually attempts to set up the call through an alternate group of trunks (such as to a tandem office) which can reach the same destination. When a marker fails to find a suitable path through the switching network due to busy conditions in the links, it makes a second attempt using a new set of links in a different part of the network. A marker may make as many as three such attempts on a single call. In case a marker encounters a trouble condition it reports this trouble, leaving a record of its nature and location in a form which can be interpreted by a maintenance man, and then proceeds to set up the call using other circuit elements.

In ordinary conditions a marker can set up approximately two calls per second. During a heavy-traffic interval in a 10,000-line office it may be necessary to set up calls at a rate of about ten per second in order to provide satisfactory service to the subscribers. Thus it is evident that more than one marker is required. From three to ten may be used, depending on the size of the office and the amount of traffic. The necessity for more than one marker means that the system is further complicated by the control means necessary to coordinate the actions of these markers and prevent them from interfering with each other.

A common control system contains a number of control units of several varieties such as registers and markers (and others which have not been mentioned), and, in addition to the interconnecting network of links to provide conversation paths, the system must evidently contain another network of control leads and interconnections over which the control units communicate with each other and test and control the switching network. These discussions indicate that a switching

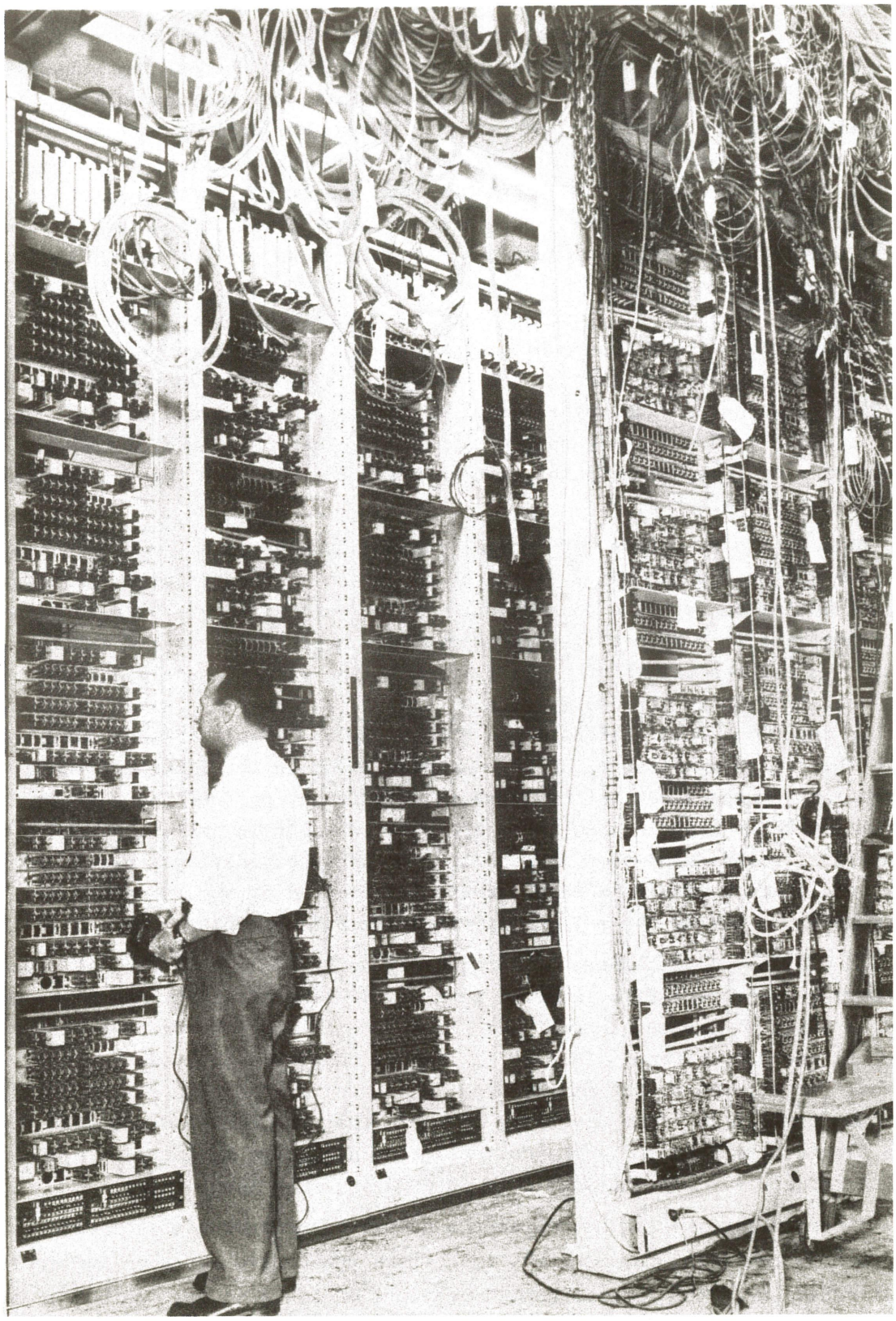


Figure 1-4 Loose Cables Awaiting the Installation of a Marker in a Dial Switching Office

system is complex, and a study of actual circuit arrangements confirms this impression. The following chapters will attempt to outline and describe certain general concepts as an aid to better understanding of telephone switching. Often the complexity is not in the basic principles of what has to be done but in the details of execution.

1.5 THE NATURE OF DETAILS

In the preceding paragraphs words such as "tell," "remember," "know," "choose," and "select" were used in discussing the actions of units in a switching system. Surprisingly, these words which are usually applied to rational mental processes express with some accuracy the nature of actions performed in switching systems. The actions, however, are not a result of independent thinking on the part of the units but are more in the nature of automatic response to control signals. The designer has analyzed the situations which may occur, determined what shall be done for each one, and built into the control mechanisms a means for recognizing the situations and reacting accordingly. The machine then "knows" what to do for a definite set of circumstances and is able to analyze a combination of preconceived conditions and produce for each condition a result which agrees with the pattern of logic laid out by the designer.

Although a switching system as a machine responds to signals from a subscriber, this is something more than simple remote control. In some systems these signals may be used directly as control signals to start and direct a train of actions. In others, the signals are merely information which must be re-evaluated in terms of the machine's own "knowledge" before effective actions are started. In either case the machine collects supplementary information concerning the interconnecting elements it controls, and as the call progresses it uses this information in making the connection or to initiate an entirely new train of actions. Some idea of the scope of actions exercised by the machine in following the subscriber's instructions is indicated by the fact that a switching system of ordinary size may provide as many as 20,000 different combinations in which interconnecting elements may be put together to form a talking path between two particular subscribers of the same central office. A call between these subscribers may use any one of these combinations, depending on the conditions encountered at the time the call is made.

At present most of the complex control is done by means of relays similar to those shown in Figure 1-5. Switches and other electromechanical devices sometimes participate, and future developments will undoubtedly see an increase in the use of tubes. Relays are particularly adaptable to switching applications and the so-called "general purpose" relays such as the U-type are built expressly for this use. These relays consist of an electromagnetic core structure wound with one or more windings and an armature which actuates as many as 26 contact springs. These springs carry contacts in various arrangements of makes, breaks, and transfers. In itself a relay is a very unimaginative device which responds as a slave by moving its springs when a circuit through its operating windings is closed. It is

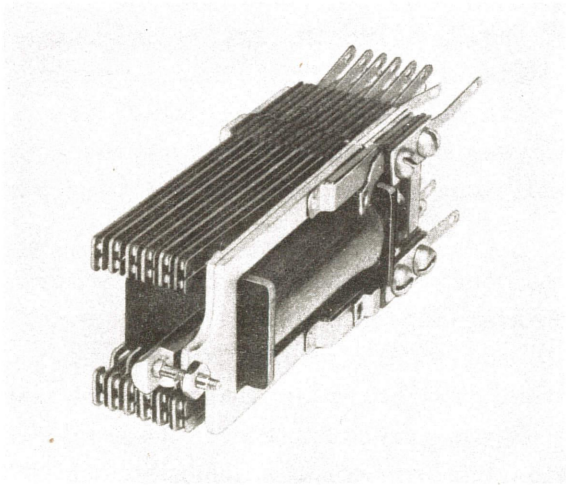
the interconnection of the contacts and windings of a group of relays in what is commonly termed a "relay circuit" that enables relays to simulate simple mental processes in relating cause and effect. The latter part of this course deals specifically with the design of such relay circuits.

A relay circuit can be built to perform any action in which cause can be logically related to effect. This of course implies that the "causes" must be capable of controlling the flow of an electric current, and that the "effects" can be accomplished by devices which can be actuated by opening and closing electrical contacts. Important characteristics of relay circuits which make them useful for control actions are:

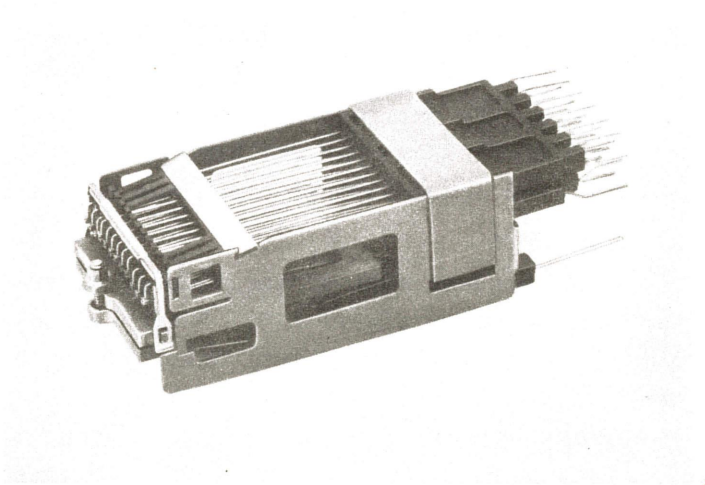
(1) The relays of a group may be operated in a number of combinations. Multiplicity of circuit paths through contacts on these relays may be constructed so that they are each independently closed for any one or more of these combinations and open for all others.

(2) A relay may operate from some external control, and having operated, remain operated from a path through contacts of the other relays of the group after the original control has disappeared. (This is called a "locking" path, see Chapter 13). The relay may be thought of as "remembering" that the original action has occurred, and it will retain this memory until it is caused to release by some subsequent action.

The action of a relay circuit depends on the relays operating in combinations in response to input conditions. These combinations open and close circuit paths to establish desired output conditions. The output conditions correspond to the input conditions. This correspondence can be made to depend on not only the combination of input conditions present, at a given instant, but, due to the ability



Flat Spring U-Type Relay



Wire Spring Relay

Figure 1-5 Typical General-Purpose Relays

of relays to "remember," can also depend on the sequence of input conditions which has previously existed. In some cases the output actions of a relay circuit react back into the circuit. For example, a circuit may transmit signals to a second circuit to start actions culminating in one of several conclusions. The second circuit then signals back to the first the nature of the conclusion reached, and the first circuit continues its actions in a manner appropriate to this conclusion.

In telephone switching there is frequent need to pass "information" from point to point, such as between subscriber and central office, or between units within a central office. This "information" may represent a subscriber's directory number or the switch location of a line or trunk. Again, it may represent a request such as "examine line X and report its condition," or a reply such as "line X is busy," or "line X is idle and may be used." In some cases information is passed by the simple act of closing a circuit path to cause a relay to operate. In others the action involves "signals" which may be thought of as a set of arbitrary symbols, just as written or spoken language is a set of symbols with assigned meanings for the purpose of conveying ideas.

For instance, one very obvious need for signals is for the calling subscriber to tell the central office the desired directory number. The signals in this case are generated by contacts in the dial mechanism which open and close the subscriber's line, furnishing a train of "pulses" equal in number to the value of the digit dialed. In some systems these signals are received by relay circuits, a circuit of about 50 relays being able to count and record a seven-digit number. Relays act in response to each pulse. The first pulse causes a relay combination to be established. The combination is "remembered" after the pulse terminates, and each succeeding pulse causes relays to operate or release to establish a new combination. The combination existing at any moment then corresponds to the number of pulses which have occurred. Each digit must be recorded separately so that, for example, a "two" and a "three" dialed in sequence are not confused with a "five." This is done by recognizing the time pause between the dialing of separate digits and using a new set of relays to remember the next digit.

It is often necessary to transmit the dialed number or other similar information between units within the switching office. This is usually done in a single action which may require the use of a number of interconnecting leads if the information is complex. In the original circuit the information is in the form of a combination of operated relays. Paths through contacts on these relays will apply conditions such as battery or ground to the interconnection leads and this in turn will cause relays in the second circuit to operate. The number of relays and their combinations in the two circuits may not be the same but there is a fixed correspondence between the two combinations. Thus the combination of operated relays in the second circuit may represent the same information in a different "code."

Relay circuits interpret received information and perform corresponding actions. For example certain digits—the office code—identify the central office serving the desired subscriber and hence in the central office of the calling subscriber these digits identify the group of trunks to the called office. When

these digits are registered on relays, a circuit path through contacts of these relays will cause the control circuit to connect to this particular group of trunks. If a different office code is dialed, a different combination of relays is operated and hence a different group of trunks selected.

A relay circuit may be required to "examine" lines or trunks to determine their busy or idle condition. For this reason a test lead is usually associated with a transmission path within the office and some condition such as "ground" may be applied to this lead when the path is used on a connection, and this condition is maintained as a busy indication as long as the circuit path is in use. A control unit may examine a line or trunk by connecting a relay to its test lead. If this relay operates, it causes the control circuit to modify its actions to send a busy signal to the calling subscriber, otherwise the control proceeds to establish the connection to this line or trunk. By means of relay circuits a control circuit may connect to the test leads of a number of trunks or links at the same time, determine their idle or busy conditions, and select a particular idle one for use on a particular call.

In modern automatic switching systems the control is by means of a number of units, each of which performs some of its actions independently but must work with other units in some stages of setting up a call. The necessity for coordinating the actions of the control circuits themselves tends to complicate a system.

1.6 CONCLUSION

As has been stated, a full appreciation of telephone switching and its problems requires a knowledge of both broad principles and of details by which these principles are realized. It is also true that the particular detailed arrangement used in a given instance is seldom of general interest since there are usually a number of arrangements similar in nature which are equally good.

This chapter is a preview of telephone switching. The next chapters—up to Chapter 12—present basic principles and general background information. The succeeding chapters discuss detailed techniques of elementary switching circuit design.

CHAPTER 2

BASIC SWITCHING CONCEPTS

2.1 GENERAL

Equipment to serve the switching needs of subscribers is concentrated in Central Offices. The fundamental purpose of a central office is to establish interconnections between circuit paths which will permit subscribers to converse with each other. The number of subscribers served by a central office will range from less than a hundred in a small rural community to about ten thousand in a single office in a metropolitan area. Switching systems must be designed to serve these various sized groups of subscribers. Increasing the size of a switching system requires more than a simple proportional increase in the amount of apparatus for making connections. As the number of subscribers increases each connection becomes more complex, since each subscriber is offered the opportunity of connecting to any other one of his fellow subscribers. No single universal plan for a telephone switching system has yet been found which is entirely suitable for giving service to subscriber groups of all sizes. Various types of switching systems for central offices have been developed and will be discussed in later chapters. These systems differ in the type of apparatus used as interconnecting devices, the pattern in which they are interconnected, and the means by which connections are controlled. All of these systems permit some variation in numbers of subscribers by adjustments of the amount of apparatus and the interconnecting pattern. However, for a particular type of system there is usually some range of subscriber group-sizes for which this type is most suitable. There are also competing types in a given size range.

Increasing the number of subscribers beyond certain critical points peculiar to a particular type of system plan usually requires for that system a considerable increase in the amount of apparatus. Between these critical points the marginal cost* of serving additional subscribers will often decrease until the next critical point is reached. These points depend on some characteristic of the switching devices or the interconnecting network plan. For example, in manual systems when the number of subscribers reaches a point where the necessary jacks, etc., cannot be reached directly by a single operator, it becomes necessary for the connection to be extended to a second operator for completion. This increases abruptly the

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*Marginal cost is the cost of adding one more item when a number of similar items is already provided.

amount of apparatus and operating expenses. In one type of automatic system which will be discussed in Chapters 4 and 5, the switches are directly controlled by the digits of the dialed directory number, and critical points occur when the number of subscribers is approximately 100, 1000, or 10,000.

In most present-day switching systems there is a top limit to the number of subscribers who may be served in one central office group. To increase beyond this number is either impossible or involves a major increase in the amount of apparatus involved. A given switching system plan is usually most economical when operating with the number of subscribers near the maximum for this system. It is always necessary for practical reasons to hold some spare capacity in reserve.

2.2 ENGINEERING OF SWITCHING SYSTEMS

When a switching system is to be provided for a certain group of subscribers, a particular type of system is chosen and adapted to the requirements of that particular group. This adaptation means determining a satisfactory quantity of switching equipment, of connecting paths, of trunks to other central offices, and so forth, and is known as engineering the central office. Engineering a central office is a complex problem involving a knowledge of the telephone habits of the subscribers, such as the average length of their conversations and the frequency with which they use the phone, daily or seasonal variations in traffic load, and possible future changes in the number of subscribers. The design of a telephone switching system must, of course, permit such engineering for a certain range of office sizes.

The problem of increasing complexity with increasing size of a switching system results in a constant urge to find schemes of interconnection and system operation which permit more and more economical use of apparatus. These schemes permit the amount and type of equipment to be adjusted (or engineered) more closely to the traffic requirements of the subscribers. To illustrate, let us contrast two basic plans, good and bad, which might be used in switching systems.

For the first plan, the poor one, suppose that switching service is provided by equipping each subscriber's line with a device which can connect to every other subscriber's line. The device associated with a particular line will stand idle except when a call is made on this line. Thus a great many devices are provided although relatively few of them are in use at any one time. This system may be said to make very inefficient use of the apparatus, where efficiency is defined as the ratio of the number of items in use at any moment to the total number provided, averaged over the period of time being considered.

The second and more efficient plan is to provide a device which is able to complete a call from any subscriber to any other subscriber. The number of these devices, then, needs be equal only to the maximum number of simultaneous calls expected which is always much less than the total number of subscribers. Variations of this basic principle of permitting a group of subscribers to share the use of switching paths or other equipment are found in all practical switching systems of any size. A system developed according to this plan can be engineered according

to the traffic load produced by the subscribers. Thus an office in a business district with high telephone usage will contain more apparatus than a quiet residential office, although both may serve the same number of subscribers.

In the design of switching systems, the capabilities of switching devices, the basic control schemes, and the economies of traffic engineering must be closely coordinated. This is the most important aspect of switching system design.

2.3 TRAFFIC ENGINEERING TERMS AND CONCEPTS

In order to properly evaluate and compare various switching arrangements, some knowledge of the more important traffic engineering terms and concepts is necessary.

If all of the subscribers of a single isolated switching system wished to talk at once, half would originate calls to the other half, and the number of connections required in the central office would be equal to half the number of subscribers. This maximum situation is most improbable. Only a fraction of the subscribers are using the phone at any given time, and the switching system is required to complete simultaneous connections for only this number of subscribers. For example, a switching system serving 5000 subscribers may never have calls from more than 10 per cent of them in progress at any given time. A quantity of equipment sufficient to complete 500 simultaneous connections would satisfy the required service. Each connection of course, could be between any two of the 5000 subscribers.

In the above example if subscriber 501 attempts to originate a call, all of the connecting equipment is busy, and the connection cannot be established although the line to which he desires a connection may be idle. This is termed a lost call and some signal such as a "paths busy" or "overflow" tone is usually transmitted to the subscriber. In practical systems a call may be lost not because the absolute call carrying capacity of the system is reached but because some group of links required for a particular connection is busy. The number of lost calls is used as one of the yardsticks of the service rendered by a switching system.

The main problem in traffic engineering is to determine how much equipment is required to give adequate service to a group of subscribers. The traffic load presented to an office will vary with the season of the year and the hour of the day. Certain hours of the day are busier than others and there are seasonal variations in these daily peaks.

Telephone systems are not engineered for maximum peak loads but are engineered for some typical busy-hour load. The busy hour is the hour period during the day in which the most calls occur. Some calls are expected to be lost during the busy hour, and the average ratio of lost calls to total calls is called the grade of service. This is usually expressed as a probability, a typical figure being P .01. This is read "probability of loss of .01" which means that on the average one call out of a hundred is lost. During severe traffic loads above the

engineered busy-hour load, the grade of service will deteriorate. Consideration must be given to these overload periods so that the grade of service does not go beyond certain limits.*

Numerical values are given to various characteristics of telephone traffic so that the requirements of groups of subscribers may be rated for engineering purposes. These are all based on conditions during the busy hour and are usually average values. The calling rate is the number of calls placed by a subscriber during the busy hour. The average holding time is the average time of one call and is usually stated in seconds. The product of calling rate and holding time gives the average number of seconds during the hour in which the subscriber "occupies" a telephone circuit. This factor is expressed in units of call-seconds, more often given in the larger unit, hundred-call-seconds, which by using the Roman C for one hundred is abbreviated CCS. A more useful unit is the call-hour which is given by converting seconds to hours, thus:

$$\text{Call-hours} = \frac{\text{CCS}}{36} .$$

As an example, suppose that data collected over a period of time shows that a subscriber originates an average of 1.2 calls during the busy hour and the average time of each call is 3 minutes. This gives:

$$1.2 \times 3 \times 60 = 216 \text{ call-seconds} = 2.16 \text{ CCS}$$

Converting to call hours:

$$\frac{2.16}{36} = .06 \text{ C. Hr.}$$

This means that this subscriber on the average requires the use of an interconnecting circuit for six hundredths of an hour during the busy hour. On this basis one interconnecting circuit would suffice for a number of subscribers. If subscribers' calls were properly placed, the interconnecting circuit would handle the average business of 1/.06 or 16.7 subscribers. We might also say that the .06 call-hour load means that on the average .06 of an interconnecting circuit is required during the busy hour to serve this subscriber.

The traffic load furnished by a group of subscribers may be stated in terms of call hours. A given load in call hours may, of course, be built up of a large number of short calls or a small number of calls with long holding times. The characteristics of various subscribers are determined by collecting extensive field data. The past history of a group of subscribers is considered when planning new installations. Certain types of subscribers are known to have certain trends in

*Such overloads may occur during emergencies such as fires or storms. Some predictable overloads also occur, such as on Christmas or New Year's Eve.

their telephone habits. For example, most business telephones are characterized by high calling rates and short average holding times, while residential telephones have relatively low calling rates and long holding times.

By adding the call-hour load presented by each subscriber, the total average traffic load offered to a central office is obtained; and in a similar manner the traffic load requirements at various points in a switching network may be estimated. For example, the traffic load requirements on a group of trunks between two offices may be stated in call-hours or CCS.

Traffic loads are usually based on average conditions during the busy hour. If only sufficient equipment to handle average loads were provided, there would be many lost calls due to temporary peak loads. Statistical methods discussed in the course on Probability and Statistics are employed to determine the proper amount of equipment required to meet a given grade of service. As an example the following tabulation gives data for a group of trunks carrying a 20 call-hour load.

TRAFFIC DATA FOR 20 CALL-HOUR LOAD

Grade of Service	Trunks Required	Trunk Efficiency
P .01	32	63%
P .001	36	56%

This data shows that 32 trunks will handle the 20 C. Hr. load with a loss of one call in 100, while 36 trunks will lose only one call in 1000. The third column shows the efficiency of the group of trunks. In the P .01 case the 32 trunks average 63 per cent busy during the busy hour. Twenty trunks worked at 100 per cent efficiency could handle a 20 call-hour load, but this is not possible in a practical system. It would mean that calls were originated in such a manner that each trunk was taken up by a new call at the exact moment that it was released from a previous connection. If a group of trunks is overloaded by an increase in the offered traffic, a larger proportion of the calls will be lost but more trunks will be kept busy. This means that the grade of service degenerates but the trunk efficiency improves during an overload.

2.4 THE BASIC PLAN OF A CENTRAL OFFICE

This section discusses in general terms the elementary principles of telephone interconnections and outlines a fundamental plan which is followed today in practical switching offices of all types. The following five chapters continue the discussion, giving more details and building an over-all picture of the functions of a complete switching system.

Originating and Terminating Traffic

From a transmission standpoint a telephone circuit is a two-way path permitting conversation between two subscribers in either direction. However, from a switching standpoint, paths in a switching network or trunks between offices are often one-way elements. Connections may be set-up or controlled through them in

only one direction. A connection originated by a subscriber A, to a second subscriber B, is an originating connection from the standpoint of subscriber A, and a terminating connection from B's standpoint.

In a connection originated by B to A the conditions are reversed. In many cases a subscriber is given the use of different equipment and circuit paths, depending on whether he originates the connection or whether he receives a terminating call. Even when paths or networks are two-way, a particular connection through them is characterized by the direction in which it was set up. Trunks between offices are spoken of as outgoing from one office and incoming to the other office. In all cases the connection, once established, provides a two-way transmission circuit.

In most switching systems a connection is established in two main stages, the originating stage and the terminating stage. This is illustrated in Figure 2-1. In the originating stage a connection is made from the calling subscriber's line to a trunk, and in the terminating stage the trunk is connected to the called subscriber's line. In many switching systems the originating and terminating stages are in fact independent, employing separate apparatus and control means. In others, economies are realized by combining the switching networks and control equipment in various degrees.

Calls between subscribers in the same office are set up through intra-office trunks which join together the originating and terminating stages of this office. The three types of trunks, outgoing, incoming, and intra-office, shown in Figure 2-1, all perform the single function of joining originating switching stages to terminating switching stages. Outgoing and incoming trunks are two ends of the same interconnecting path, the outgoing trunk of one office being the incoming trunk of another office. An intra-office trunk is actually an outgoing-incoming combination connecting the two halves of a single office.

The originating-terminating breakdown permits all connections from subscriber to subscriber to follow the same general pattern. The originating connection is from the calling line to one of a group of trunks to the desired

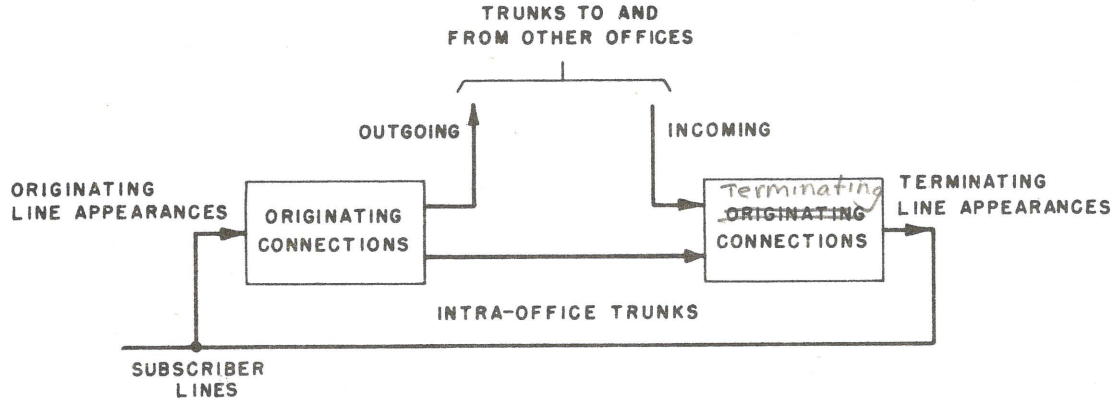


Figure 2-1 Originating and Terminating Connections

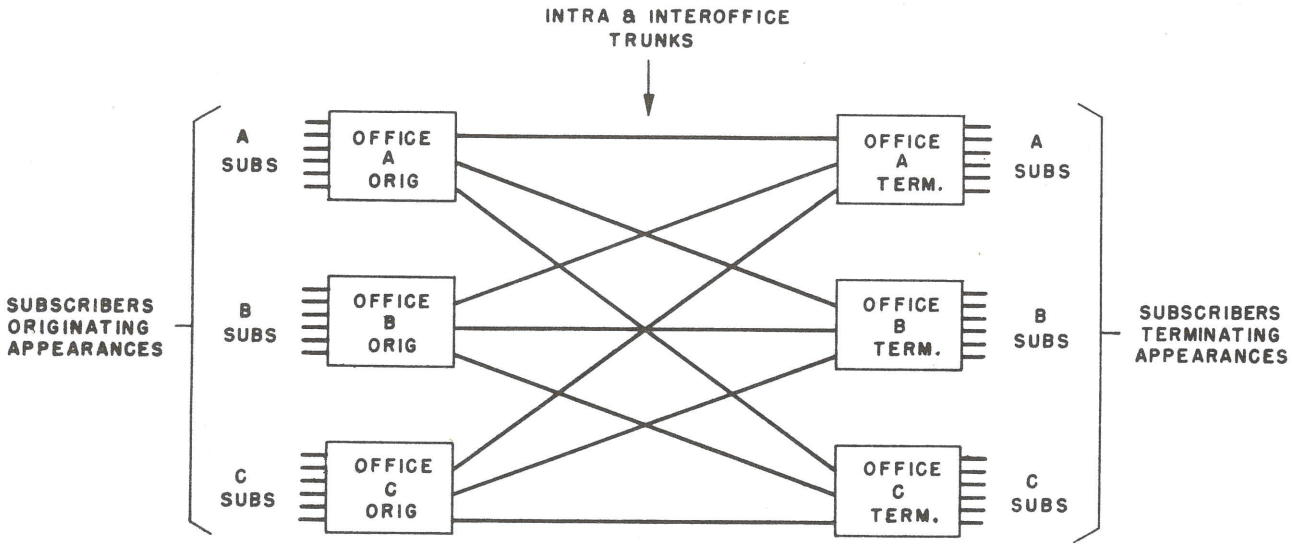
terminating office. The trunking interconnections of three offices are shown in Figure 2-2. Note that the two stages of each office are effectively independent and function in a similar manner whether working with the other stage of the same or of a different office.

Concentration and Expansion

In the basic plan of a telephone connection as shown in Figure 2-1, each conversation requires the use of a trunk. The number of trunks in a switching system determines the maximum number of simultaneous connections that can be made. This obviously is less than the number of subscribers, and in practical cases the number of trunks is closely apportioned to the subscribers' needs to give the desired grade of service. The originating stage of a system then must concentrate the traffic so that a large number of subscribers on the input side of this stage can have access to a smaller number of trunks on the output side. This is accomplished by various schemes of interconnecting the switching devices and will be discussed in detail in Chapter 4.

For general discussion a concentrating stage of switching may be indicated by the symbol shown in Figure 2-3A. The inputs on one face of the figure can be connected internally to the outputs on the other face. The width of each face indicates the relative number of terminals on that face. A given connection is between a single input and a single output so that the maximum number of simultaneous connections is equal to the access on the narrow side. In general, any switching network may be represented by figures such as A, B, and C in Figure 2-3.

Again, in the terminating connection the number of incoming trunks is much less than the total number of subscriber lines, and the interconnecting network must expand to give sufficient access. An expansion network such as Figure 2-3C



is used in these cases. In an ordinary office originating and terminating traffic is about equal and the concentration and expansion networks are similar in size and shape. In many systems these two networks for serving the same group of subscribers are combined.

Basic Switching Network

A basic switching network is shown in Figure 2-4. This consists of a concentration stage followed by a distribution stage for the originating connection, and a similar distribution stage feeding into an expansion stage for completing a terminating connection. The originating and terminating halves of the interconnection network are quite similar although different procedures are required when setting up connections through them. Principles developed below for the originating network can also be applied to the terminating network with only minor modifications.

In the concentration network of the originating stage the originating lines compete with each other for a connection to the distributing stage. The distributing stage has the same number of inputs and outputs and provides a means of selecting a trunk to the desired terminating office. The concentrating and distributing stages are often quite distinct in actual switching systems but in some cases are combined.

The concentrating stage in Figure 2-4 serves only to reduce the number of switching paths, a particular group of inputs always having access to a given group of outputs. A selecting action is accomplished in the distributing stage. Usually any input to the distributing stage has access to every output (trunk) of this stage. Since the outputs of the distributing stage are groups of trunks to the various terminating offices, each input must certainly have access to trunks in every group but not necessarily to all trunks in each group. When the access of the switching devices is limited, the individual inputs may only have access to a sufficient number of trunks in each trunk group to provide the desired grade of service.

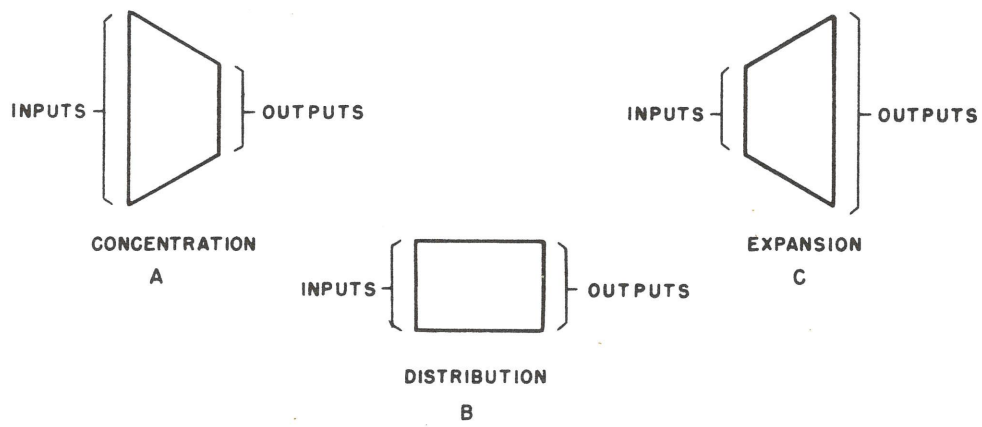


Figure 2-3 Types of Switching Networks

The switching network must be tailored to fit the requirements of a definite group of subscribers. In the concentrating stage the width of the input is determined by the number of subscribers, while the width of the output is determined by the call-hours of traffic originated by these subscribers. Examples are shown in Figure 2-5. Figures 2-5A and B represent originating networks serving the same number of subscribers. Network A has more concentration than B and therefore can accommodate fewer call-hours of traffic. The larger capacity of the B network may be required because the B subscribers have a higher calling rate, longer holding time, or both. The network C would be used for a smaller number of subscribers who originated the same amount of traffic as those of B.

General Actions in Switching Networks

Connections in switching networks are the result of two general types of actions. These are selecting and hunting. In performing a typical selecting action, the switching device of a network is directed to connect to a particular circuit path and must connect to this path only. If a busy condition is encountered, the connection is refused. In a hunting connection a number of circuit

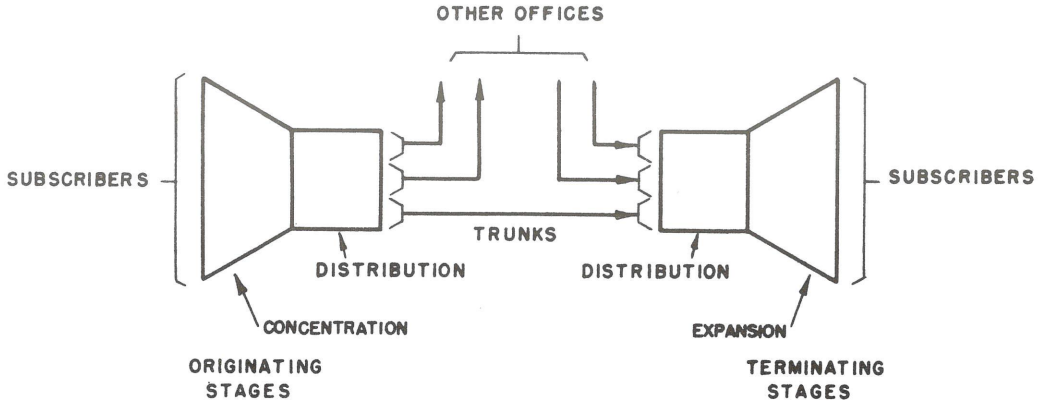


Figure 2-4 Basic Switching Network

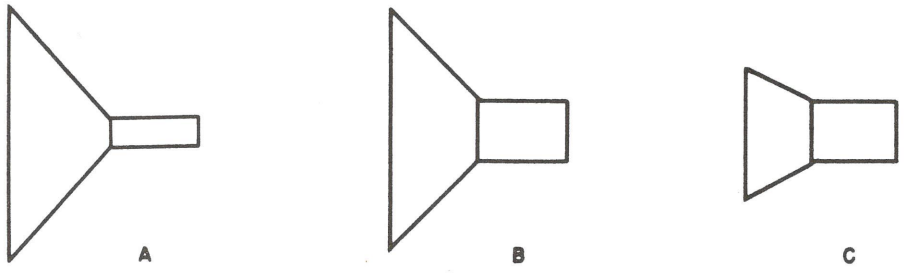


Figure 2-5 Adjustment of a Network According to Traffic

paths are equally satisfactory, and the switching devices hunt over the group and connect to some one path which is found to be idle. The hunting may be done in time sequence or a number of circuits may be examined simultaneously and an idle one chosen.

A selection may be that of a particular group of paths. For example, in an originating connection a group of trunks to the desired destination is first selected and then the switching devices hunt over this group for an idle trunk.

The information for controlling a selection is obtained from outside the switching network, while the hunting connection is controlled from within the network, depending on the busy or idle conditions of the circuit paths involved. In a broad analysis, selections are specifically requested by the calling subscriber when he passes into a switching system the telephone number identifying the desired subscriber. This information is used to direct the switches toward paths leading to the requested line. Equally important, however, are the connections made on a hunting basis. Hunting permits a number of subscribers or even an entire office to share the use of a group of circuit paths on an equal basis. This is one of the most important principles for providing economical service in telephone switching networks. It permits circuits to be arranged for common use so that service is not denied merely because particular paths are busy while other equally satisfactory paths stand idle.

Let us now examine a little more closely the actions taking place in the originating stages of a switching network. In the concentrating stages a given subscriber does not always obtain a connection to the same output terminal but competes with other subscribers for idle outputs in a group.

In Figure 2-6 a group of subscribers, S_1, competes within itself for a given group of paths, C_1, in a concentration stage. Each subscriber in S_1 can connect to any path in C_1 but not in C_2 to C_n. This is a hunting action. The number of paths in a group such as C_1 at the concentration stage is often determined by the access size of switching devices and may vary widely.

In some system plans the path group C is held constant in size, and the number of subscribers in a group S is adjusted according to the traffic load in call

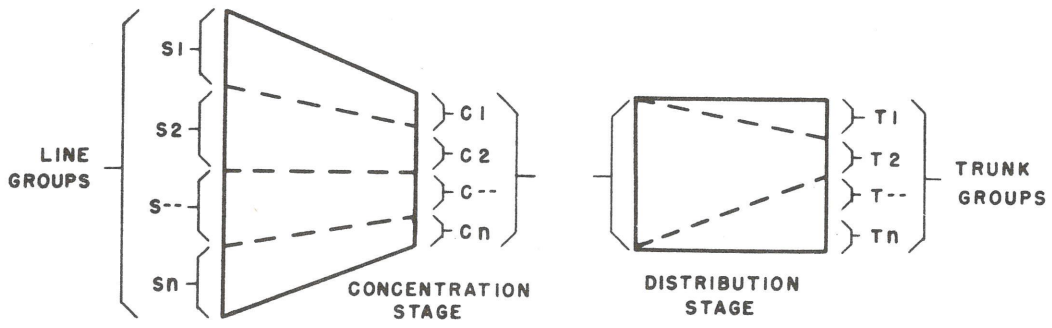


Figure 2-6 Concentration Toward a Particular Trunk Group

hours. In others the number of subscribers S in a group is fixed, and the size of a path group C is adjusted to the requirements of this group of subscribers. Within a single switching office the concentration between corresponding groups S and C may vary from group to group.

In the distributing stage both selecting and hunting take place. In some systems these two actions are intermingled so that specific actions cannot be assigned to individual switching devices. This is particularly true in the more modern systems discussed in the following chapters. Such networks are quite involved and must be grasped in their entirety if they are to be fully appreciated.

From the standpoint of each output trunk group the distributing stage also serves to concentrate traffic to this group. This is indicated by the dotted lines in Figure 2-6 for a particular trunk group T_2. All of the paths in the groups C_1,---C_n at the concentration stage have access to trunks in T_2 (or to any other selected group). In an ideal case all of the individual inputs to the distributing stage from the C groups may be considered as a single large input group, each of which has access to every trunk in T_2. In practical cases limitations of the switching devices may permit given inputs to have only partial access to the individual outputs of a group. Normal traffic spreads out over all of the output trunk groups rather than concentrating in a single output group, so that competition for a particular output group in a distribution stage is not severe except in unusual traffic conditions. The trunk groups lead to different destinations and their sizes are adjusted according to the average amount of traffic for these destinations.

2.5 EFFECT OF GROUP SIZE

Large groups of switching paths or trunks are more efficient in handling traffic than small groups. A detailed discussion of this subject is given in the course on Probability and Statistics, but since the principle has considerable influence on the basic philosophies of switching system design, a brief discussion is given here. The discussion applies to groups of circuit paths which are chosen by a hunting process. This means that each path (for example, trunk) in the group is equally capable of providing the required service and any idle one may be used for a given connection.

The number of simultaneous calls presented to a group of paths will fluctuate about some average, with peaks above and dips below this average value. For a satisfactory grade of service the number of paths in the group must be above the average and near the peaks so that the number of times the calls presented exceeds the number of trunks agrees with the desired grade of service. In large groups the calls have a better chance to "average out" and peaks are not relatively as high above the average as in small groups. This is consistent with general experience of events occurring at random and is borne out by telephone traffic studies. The effect is apparent if we consider a large group divided into a number of small subgroups. Peaks of traffic in one subgroup may find all paths busy and calls will be lost although other subgroups may have idle paths. When all paths are in a

single large group no calls are lost until all possible paths are busy. An example taken from traffic engineering tables which shows the effect of group size is tabulated below.

GROUPING OF CIRCUIT PATHS FOR P .01 GRADE OF SERVICE

No. of Groups	Paths Per Group	C. Hr. Per Group	Total Call-Hours	Group Efficiency
4	10	4.1	16.4	41%
2	20	11.1	22.2	55%
1	40	27	27	67%
1	27	16.3	16.3	59%

The first three rows of data compare different subgroupings, of 40 trunks. The first row shows that four groups of ten paths each can handle 4.1 call-hours per group, or a total of 16.4 call-hours. This means that a traffic load which averages 16.4 trunks busy will cause a loss of one call in a hundred (P .01 grade of service) if 40 trunks are used in four independent subgroups. Two subgroups of 20 each will handle a total of 22.2 call-hours with the same grade of service, while if the inputs are given full access to the 40 trunks as a single group, 27 call-hours of traffic can be carried. As a further comparison we may determine the number of trunks in a single group sufficient to carry the 16.4 call-hour load handled by the four groups of ten. As shown in the last row of the tabulation 27 trunks in a single group will carry 16.3 call-hours. The efficiency of the trunks is given in per cent in the last column of the table and we see that large groups are more efficient than small groups.

The above discussion points out the desirability of arranging circuit paths in large groups. There are a number of practical reasons why this cannot always be done. The most outstanding reason is the limited access of switching devices. If a number of circuit paths are to act as a single group, each input when hunting within this group for an idle path must have access to every path in the group. This means that either the switching devices must be large and have great access to accommodate the large group, or more switching devices must be used in the network. An economic balance must be reached between the quantity of switching devices and their control means and the number of required circuit paths. In the interconnecting network within a switching office, paths are inexpensive and the less efficient small subgroups are often used. In other cases, such as trunks between offices, additional switching equipment necessary to give full access to an entire group is often justified by a saving in the cost of outside plant. In certain types of automatic systems there are equipment items, such as control mechanisms, which are quite expensive and are used by groups of subscribers on a common basis. These are usually arranged for access as a single group in order to achieve the best efficiency of use. Greater efficiency of use offsets the increased complexity of the access network.

Another reason for the existence of small groups is that the traffic load may require only a small number of circuit paths. Trunking between central offices, where the traffic between two offices does not justify a large number of trunks, is an example.

2.6 IMPROVING THE EFFICIENCY OF SMALL GROUPS

We have seen that one of the principal reasons for the occurrence of small groups of paths in switching systems is the access limitation of switching devices which forces the subdivision of large groups into small subgroups. The efficiency in these cases can often be improved by a principle which is one of the more important ones in modern switching systems and appears in many forms which often do not bear an outward appearance of similarity. It is the common overflow principle and will be described by examples rather than defined.

Consider a number of trunk groups each receiving traffic from a respective group of inputs. The number of busy trunks within each group will vary from moment to moment. During traffic peaks some groups will become all busy and additional calls presented to these groups will be lost. The groups may be engineered to contain an additional number of trunks in order to take care of these occasional peaks. If a means is provided to take care of these "overflow" calls occurring when all trunks in a group are busy, the groups can be kept smaller and the trunks used more efficiently. Moreover, if the originating traffic is random in nature, all groups are not expected to overflow at the same time, and the total number of calls overflowing from all groups at any one time will not be excessive.

The diagram of Figure 2-7 illustrates the common overflow principle. Inputs

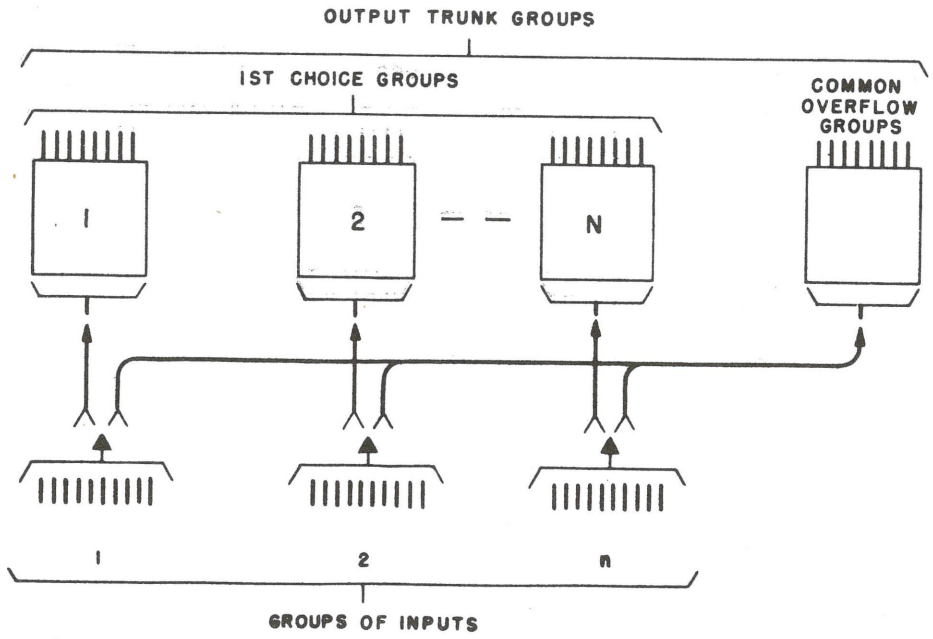


Figure 2-7 The Common Overflow Principle

are given access to individual first choice trunk groups and also to an overflow group shared in common by all input groups. The hunting procedure in locating an idle trunk is that each input group hunts first over its individual group of trunks, and when these are all busy proceeds to hunt in the common overflow group. A particular call then is not lost until its individual first choice trunk group is all busy and the common overflow group is also all busy. Since no input seeks a trunk in the overflow group until the trunks in its individual group are exhausted, it is evident that the individual groups will be well-loaded when the common group becomes all busy and calls are lost.

A comparison of a typical common overflow grouping with other groupings of 30 trunks engineered for P .01 Grade of Service is given below:

Grouping No. of Groups	Trks. per Group	Total Call-Hours	Trunk Efficiency
3	10	12.39	41.3%
2	15	14.96	49.9%
(2 individual (1 common overflow	10) 10)	17.61	58.7%
1	30	18.74	60.2%

The common overflow arrangement having two individual groups of ten trunks with each group overflowing into a single common group of ten has an efficiency of 58.7 per cent. This is not quite as good as the best possible arrangement which is a single group of 30 but is considerably better than the two arrangements shown in the table which employ smaller groups. The tabulation does not give the complete picture since the more efficient arrangements are obtained by increasing the amount of switching equipment. The amount of switching equipment increases as the efficiency increases, but not necessarily in the same proportion. This can best be evaluated by a study of particular cases, some of which are described in the following four chapters. The most economical over-all arrangement is determined by weighing the increased trunk efficiency against the increased cost of switching equipment giving access to these trunks.

The saving in trunks necessary to carry a given traffic load will often pay for a considerable amount of switching apparatus. The term "trunk" as used above should be thought of not merely as a pair of wires forming a talking path but also as any control or switching equipment which is associated with an individual link in a switching network. Links within a switching office may thus represent a considerable amount of apparatus although the length of the talking path is negligible. Economies can often be realized by grouping these links for more efficient use.

The common overflow principle appears in a variety of forms and they are covered more explicitly in later chapters, particularly Chapters 4 and 5. One quite common version is to provide for each input a switching device with enough access to accommodate the individual group as well as the common group. The control circuits are arranged to start from a normal position and search over the access terminals in a fixed order of preference. If the trunks in the individual

group are placed on terminals of earlier preference than the common trunks, then no common trunk will be taken by an input unless all of its individual trunks are busy. This is the basic principle of the "graded multiple" discussed in Chapter 4.

The terms "second trial," "alternate route," and "reserve group" are often loosely used to refer to the common overflow principle in common control systems, although these terms also have meanings not related to common overflow arrangements. In these arrangements access to only one group, individual or common, is made at any one time and the trunks or links within this group are tested simultaneously and an idle one chosen. In the all-trunks-busy condition a second trial is made in the other group. The common control circuit uses the same apparatus to test each group.

CHAPTER 3

SWITCHING SYSTEM PRINCIPLES, PART I—GENERAL

3.1 INTRODUCTION

"Switching System" is a comprehensive term which, in the field of telephone communications, may embrace the means of interconnecting subscribers within groups ranging in size from a nationwide population down to an isolated community of a few individuals. These extremes are illustrated by the common use of such expressions as "nationwide dialing system" and "C.D.O. system" (community dial office). Fortunately, the basic principles which underly the broad philosophy of all telephone switching systems can be developed by examining the connecting and control requirements of a particular type of switching center. This is true even though from a traffic standpoint such switching centers as community dial offices, local central offices, tandem offices, and toll offices appear different in nature.

It is convenient in discussing switching systems as entities (involving interconnection and control means) to take as the basic switching unit the local central office. The switching and circuit requirements of a central office are in a general sense the basic requirements of any telephone switching system. Toll, tandem, and community dial traffic, of course, introduce some special and additional requirements of their own which are not necessary in a purely local central office. However, these special requirements can usually be met by the switching techniques developed for local central offices. Furthermore, the same basic functions are involved in all these switching centers as in local switching. This being the case, the local central office will be taken as the switching system unit in the following discussion of switching philosophy. It will be satisfactory in a later chapter to describe the requirements of the other types of centers and the general techniques of meeting them.

In the development of the principles of telephone switching systems in Chapters 3, 4, and 5, the attempt will be made to keep the discussion on as general a plane as possible. This will involve some mention of techniques and methods which are logical and possible solutions to requirements, but are not necessarily in use at the present time. Such methods may be under current development or planning, or, in a few cases, may appear impractical in the present state of technical knowledge. However, specific examples will usually be drawn from present-day working systems.

Since Chapters 3, 4, and 5 constitute a development and statement of basic principles, they will be concerned only a limited extent with details. Later chapters will carry the principles on to the design of systems and working circuits, and will also introduce additional principles which only become intelligible in relation to the more detailed requirements of systems.

3.2 THE CENTRAL OFFICE AND ITS BASIC SWITCHING FUNCTIONS

The central office is fundamentally a self-contained entity which forms a junction point for subscribers' communication paths and communication paths to and from other central offices. This is indicated schematically on Figure 3-1. The communication paths are conventionally wire lines, but they may consist of any other means, such as radio which provides talking channels.

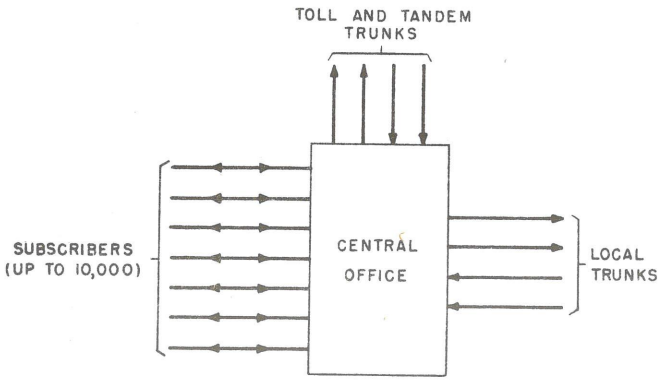


Figure 3-1 Representation of Central Office

Each subscriber line is assumed to have connected at the subscriber terminal an instrument which includes transmitting and receiving means both for talking and signaling purposes. The talking apparatus is designed to function with the voice transmission means employed by the particular central office. The signaling apparatus must also be of a type suitable to function with whatever equipment the central office employs to receive information from the subscriber on an originating call, and on terminating calls, to notify the subscriber of the arrival of a call. This subscriber apparatus is basic and must always be provided, although it may vary in type depending upon the particular switching system in use. In addition there may be equipment for special facilities such as switching on the subscriber's premises.

The primary function of the central office itself is to provide means for connecting each subscriber's line to any other subscriber's line in the same office, to any incoming trunk from another office, or to outgoing trunks to other offices. From the point of view of the subscriber, a switching system is something to which his telephone is connected and which, upon receipt of appropriate directions, will connect him to any other desired telephone. In addition to this, there have developed through the years many specialized services which subscribers have come to expect and which have a profound effect upon the design of switching systems. For the most part, however, these auxiliary facilities, many of which will be described in succeeding chapters, are side branches upon the main trunk of system switching principles. The principles are basic and are affected only in execution by the auxiliary facilities.

If the basic problem, then, can be considered the interconnection of subscribers upon receipt of appropriate directions from the calling subscriber, what are the primary functions which the central office must perform no matter what type of switching system is under consideration? When these unvarying functions have been specified, it is possible logically to develop different types of systems which can perform the functions. Analysis of the abstract switching problem and comparison among working systems produces a set of eight basic functions. It is difficult to conceive of any system which does not include all eight functions (with one possible exception) and yet remain practical, although additional functions may enter into particular systems. The eight basic functions of a central office or switching system are listed below with a brief description of each.

1. Interconnecting Function

This is one of the two most significant of the basic functions. The interconnecting function must be capable of providing private talking paths between each subscriber and all other subscribers in the office and also with the incoming and outgoing trunks. It has been pointed out in Chapter 2 that it is not practicable to provide permanent individual paths from subscriber to subscriber. Rather, a limited number of common paths are supplied which may be linked together in combinations. The facility and economy with which the interconnection paths may be established is to a large extent a measure of the performance value of a particular switching system. Not only is the interconnecting function the backbone of any switching system, it is also important in its profound relationship with the other coequally significant basic function, designated the control function. The interconnection means and the control means fundamentally cannot be judged apart. The development of one depends upon the other; broadly speaking, certain interconnection means require certain control means and to a large extent the reverse is true.

2. Control Function

By control function is meant the means by which the interconnecting function is controlled to establish a particular path between two terminal points. It consists of the equipment which, upon receipt of appropriate information from an external source, assumes control of the interconnecting function and sets up the desired connection. In some cases it may set up an alternate connection if the desired one is impossible for any reason. The control function is exercised only at the time of establishing a connection and thereafter is either quiescent or is made available for other calls.

The control function, as perhaps its definition implies, is in general the most complex of the basic functions. It is the integration of a great many secondary functions which together control the switching network or interconnecting function. Since these secondary functions vary from system to system, they cannot individually be considered basic.

Control, like the words system or function, is a general type of term and has different connotations depending upon the use. However, when applied to switching system functions, by definition the control function signifies only the means of controlling the interconnecting function.

The control function may be of several basically different types. Together with the interconnecting function, the control function determines the particular classification into which a switching system falls. Differences in the control and interconnection means produce switching systems varying not only in methods of operation but in fundamental principles.

3. Alerting Function

When a connecting path has been established to a desired point, either to a subscriber's line or to a central office trunk, signaling means must be employed to notify the destination that a call is arriving. The means whereby this action is performed is designated the alerting function. The most familiar example of the alerting function is the transmission of a ringing signal to a called subscriber to inform him of the arrival of a call. An alerting action to which the central office is responsive is performed by the subscriber when he lifts his receiver from the switchhook at the beginning of a call.

4. Attending Function

This function is complementary to, and always appears in conjunction with, the alerting function, although the two functions are usually physically removed from each other. It is the means of taking heed of an alerting signal from the remote point, which may be either a subscriber originating a call or another central office extending a connection. Its response sets into play the central office equipment that will serve the call. This function is, in general, the least complex of the basic group. Its importance is based upon the fact that individual means responsive to call-arrival signals must be provided even though all other equipment in the office is for common use.

5. Information Receiving Function

This function is provided by the means which accept instructions as to the destination of each call. The instructions may originate from a subscriber or another central office. It is obvious that this function is always necessary since, from within the central office, the destination of calls cannot be foretold.

The information receiving function, as is true of most of the other basic functions, does not necessarily appear as a separate and distinct equipment unit in the various types of switching systems. For example, in certain systems information reception and interconnection control are so intermingled as to be practically indistinguishable.

6. Information Transmitting Function

This is the companion function to information receiving. The two functions are always utilized simultaneously over a connecting path, although they may be widely separated physically. In the general case where central offices are interconnected, the information transmitting function is located in the originating office, whereas the receiving function is located in the terminating office. In some cases the central office transmitting function degenerates to repeating or merely providing a through path for the signals originating at the subscriber's instrument or a previous central office. In the limiting case in which a single office constitutes the entire system, the function is not necessary within the central office.

7. Busy-Testing Function

Except in a few unusual cases, a switching system must never permit completion of a connection to a line or a trunk that is in use. Neglect of this requirement would affect the privacy of telephone conversations and hence destroy in great measure the usefulness of any switching system. Therefore, before any switching path is cut through, the terminal point must be tested for a busy condition. The busy-testing function is usually associated with the control function and perhaps can be considered as included therein. However, its fundamental importance in switching philosophy justifies its inclusion as one of the basic functions.

There is another type of busy test which, however, is a definite part of the control function. This, in a multistage switching system, is the means by which the control function chooses idle links to build up a complete connection.

8. Supervising Function

When a talking connection has been established as a result of the interplay of the first seven basic switching functions, the path must be maintained until either or both of the terminal points disconnect. The release (or holding) of the talking path is under control of the supervising function which includes means either for continuously detecting the status of the terminal lines or trunks, or for responding to release signals. The release action itself may be either spontaneous at the appropriate time or may require auxiliary control means to effect it. The supervising function may cause release of the talking channel either as a result of disconnection by one or by both of the terminal points.

In addition to the primary function of supervising an established connection, supervision must also be provided as part of the control and information receiving functions in order to permit release during the setting up of a telephone call.

The manner in which these eight basic functions are interrelated varies, depending upon the particular switching system under consideration. The integration of the basic functions usually involves subsidiary functions, such as access means, which can only be discussed in relation to particular types of systems. In addition, as has been mentioned before, present-day switching practice includes a

great many auxiliary functions which provide facilities for enhancing the convenience and usefulness of the telephone plant to the subscriber and operating companies. Many of these auxiliary facilities and services will be described in future chapters.

3.3 A SIMPLIFIED REPRESENTATION OF A CENTRAL OFFICE

In order to illustrate the place of the basic functions in a switching system, a simplified and somewhat theoretical central office of the manual type will at first be described. Although the present trend in switching is toward completely automatic operation, many of the fundamental principles can most easily be understood in relation to the manual type of operation. In fact, some of the most advanced types of automatic switching tend to approximate the manual systems with the operator replaced by electromagnetic or electronic circuits.

The simplified manual-type switching system or central office is shown on Figure 3-2. The subscriber lines and the incoming and outgoing trunks terminate on jacks which appear in front of an operator. If the amount of traffic is too great for a single operator to handle, the line and trunk appearances will in general be duplicated before several operators.

The line and trunk jack appearances together with a group of double-ended cords which may be plugged into the jacks constitute the interconnecting function. It can be seen that by means of the cords any subscriber can be connected to any other subscriber or to any incoming or outgoing trunk. The number of cords supplied is related to the peak expected traffic, and is always much less than half the number of jack appearances (which would be the maximum possible usage since two jacks are used per connection). This is an example of concentration as discussed in Chapter 2. Furthermore, since any cord may be used to complete a connection to any terminating jack, the cords also embody the "distributive" stage of a switching system. This stage, as will be described later, appears separated from the concentration stage in most automatic switching systems.

There are many possible arrangements of subscriber jack and trunk jack appearances with associated cords, most of which can be carried over in principle to automatic systems. For example, each subscriber's line is often connected to separate originating and terminating appearances which are located at different switchboards. The switchboard containing originating line and outgoing trunk appearances is known as the "A" board. Terminating line and incoming trunk appearances are at the "B" board. Interconnection between switchboards is by trunks which appear as outgoing trunks at the "A" board and incoming trunks at the "B" board. Often the incoming trunks terminate at the "B" board as single-ended cords.

The attending function is performed by a lamp associated with each subscriber line or incoming trunk. The lighting of the lamp notifies the operator, who functions in a control capacity, that a call awaits service. Usually there is associated with the attention signal a cut-off feature which removes the signal when the request for service has been acknowledged. It is worth noting that the attending function must be allied with each individual line or trunk.

It is typical of the manual system that several of the basic functions are concentrated in the operator as indicated on Figure 3-2. As will be seen later, dispersal of these functions into separate equipment units is usually necessary in automatic switching systems.

When an attention signal appears before the operator, she must first respond as the control element in the system. This involves determining which cords are busy and idle, selecting an idle one and plugging the originating end of the cord into the calling line or trunk. This is one of several independent control actions which the operator must perform.

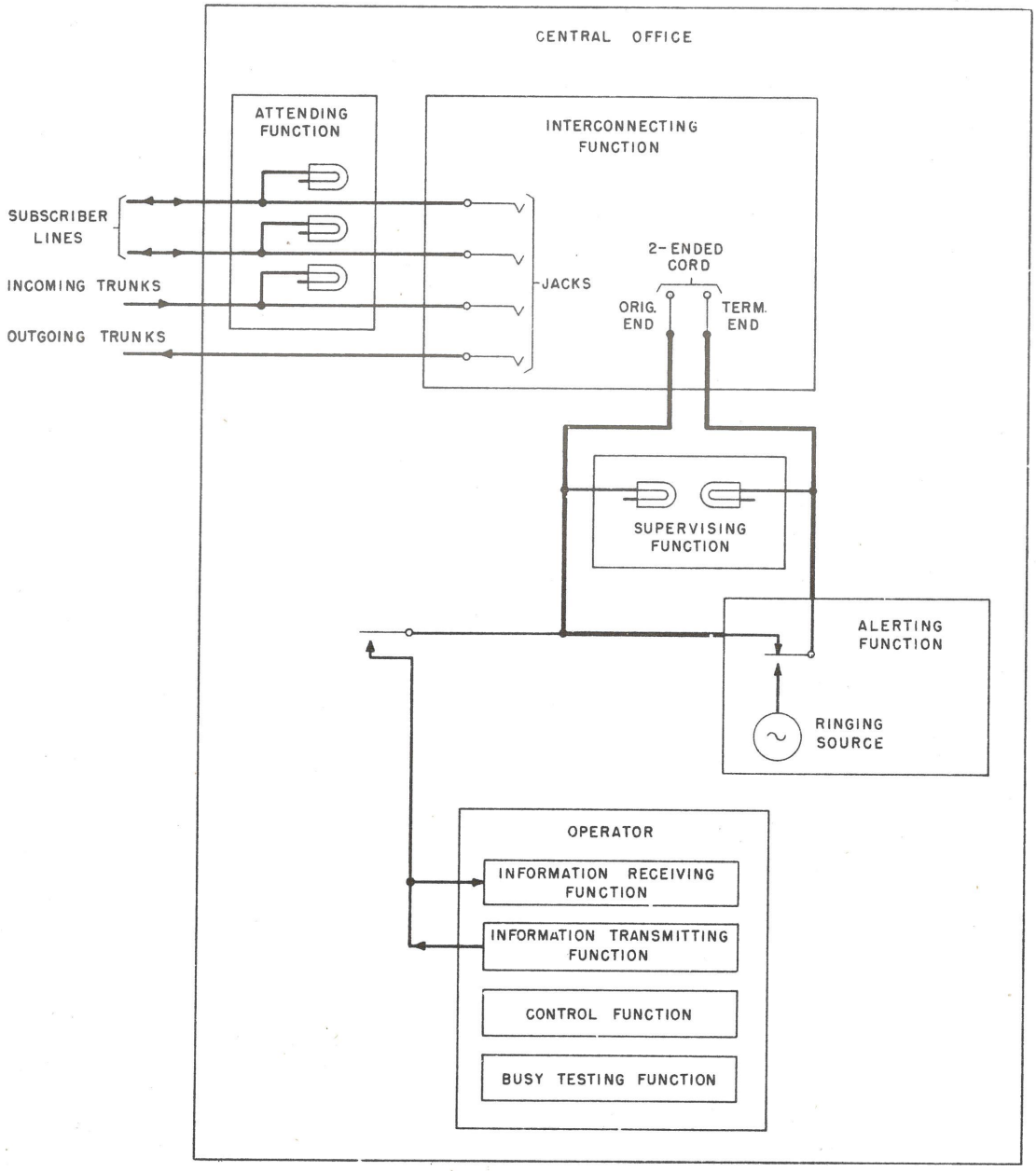


Figure 3-2 Manual Type Office—Illustrating Switching Functions

At the same time that the cord-jack connection is established, the operator's telephone set is associated with the cord so that in effect the subscriber has been connected to the information reception equipment. This function also is performed by the operator. The information as to call destination is transmitted orally* in manual systems and is registered in the mind of the operator. In automatic systems, specific circuits accept and register coded information from the subscriber.

Having received the number, the operator again assumes the control function. She translates the called subscriber's number or office code into a jack location on the switchboard and prepares to plug the terminating end of the cord into the specified line jack or one of the specified trunk group. Since there are more terminating jacks than cords, this stage is an example of the "expansion" stage of a switching system.

Before the operator completes to the terminating jack, she must perform the busy-test function to make sure that the desired circuit is idle. If each line or trunk has only one appearance, this involves only visual inspection by the operator; in the more usual case of multipled appearances, the operator utilizes an audible signal as she makes contact of cord with jack.

When the terminating cord has been plugged in**, the alerting function must be called into play. This function may be under control of the operator or not, depending upon the design of the system and upon whether the call is directly to a subscriber or to another switchboard. If the call is to a subscriber, the alerting signal is usually application of ac current which rings a bell at the subscriber's premises. Other signaling techniques are more frequently employed when calling another central office. The design of the alerting function must be such that if ringing is employed, the signal is disabled when the call is answered at the distant end.

If the call is to another office or to a "B" switchboard, the operator must perform her next function of information transmission. This is usually oral in manual systems, but if the call is to an automatic office, the operator may employ some coding means.

When the connection has finally been established and answered, the final function of supervision takes over. This is performed by lamps in the system of Figure 3-2, which indicate if either or both terminals have disconnected. In this system, the operator as control element must react to the signal and pull the connection down. In automatic systems it is more usual for the connection to hold to the supervisory function and to release automatically when either or both subscribers hang up.

The next section of this chapter will discuss the manner in which the basic switching functions fit into a typical automatic switching system. In order to

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*When the call is from an automatic switching office to a manual office, the called line number may appear on a bank of numbered lamps in front of the operator. This system is known as panel call indicator or P.C.I.

**If a line or trunk group is busy the operator may plug into a special jack which returns a tone signal or may report the condition orally.

facilitate the transition from the manual example to the automatic example, the actions of the various functions during a complete call are listed in tabular form (Figure 3-3) in order of occurrence. In the table taken as a whole, it is assumed that the call is from a subscriber in central office X to a subscriber in another central office Y. Both offices are identical and are of the form shown in Figure 3-2. If an intraoffice call is assumed, items 5 through 11 marked with an asterisk should be omitted. Note in the table that the control function is subdivided into several groups of control actions.

	FUNCTION	ACTION
1.	(ALERTING—function located outside central office)	Subscriber lifts receiver from switchhook.
2.	ATTENDING	Lamp lights adjacent to line jack.
3.	CONTROL (A)	Operator as control function reacts to attention signal by choosing an idle cord, plugging it in line jack, and throwing key to associate her telephone set with cord. Designate this as control action (A). The plugging of the cord into the jack removes the attention signal.
4.	INFORMATION RECEIVING	Operator says "number please" and receives called line number.
5.	*CONTROL (B) and BUSY TEST	Operator locates Y outgoing trunk group, chooses idle trunk by busy test, and plugs cord in trunk jack. Designate this as control action (B).
6.	*INTERCONNECTING	The first half of the connection has now been established.
7.	*ALERTING	The act of plugging the cord into the trunk jack sends an alerting signal to office Y.
8.	*ATTENDING	Lamp lights at office Y adjacent to incoming trunk jack.
9.	*CONTROL (C)	Operator Y chooses idle cord, plugs into incoming trunk jack, and throws key to associate her telephone set with cord. Designate this as control action (C), although it is similar to control action (A).
10.	*INFORMATION TRANSMITTING	Operator X (after receiving ready signal) repeats called line number.
11.	*INFORMATION RECEIVING	Operator Y (having given a ready signal) receives called line number.
12.	CONTROL (D) and BUSY TEST	Operator locates called line jack, tests that line is idle, plugs cord in jack and sets ringing key. Designate this as control action (D) although it is similar to control action (B).
13.	INTERCONNECTING	The remainder of the interconnection has now been established.
14.	ALERTING	Ringing key applies ringing current to called subscribers line. When subscriber answers, key is restored.
15.	SUPERVISION	While subscribers are talking, associated supervisory lamps stay dark. When subscribers hang up, lamps light.
16.	CONTROL (E)	When supervisory lamp lights, operator pulls down cord, restoring connection to normal. Designate this as control action (E).

*If intraoffice call, omit items 5 through 11.

Figure 3-3 Table of Switching Functions in Manual Interoffice Call

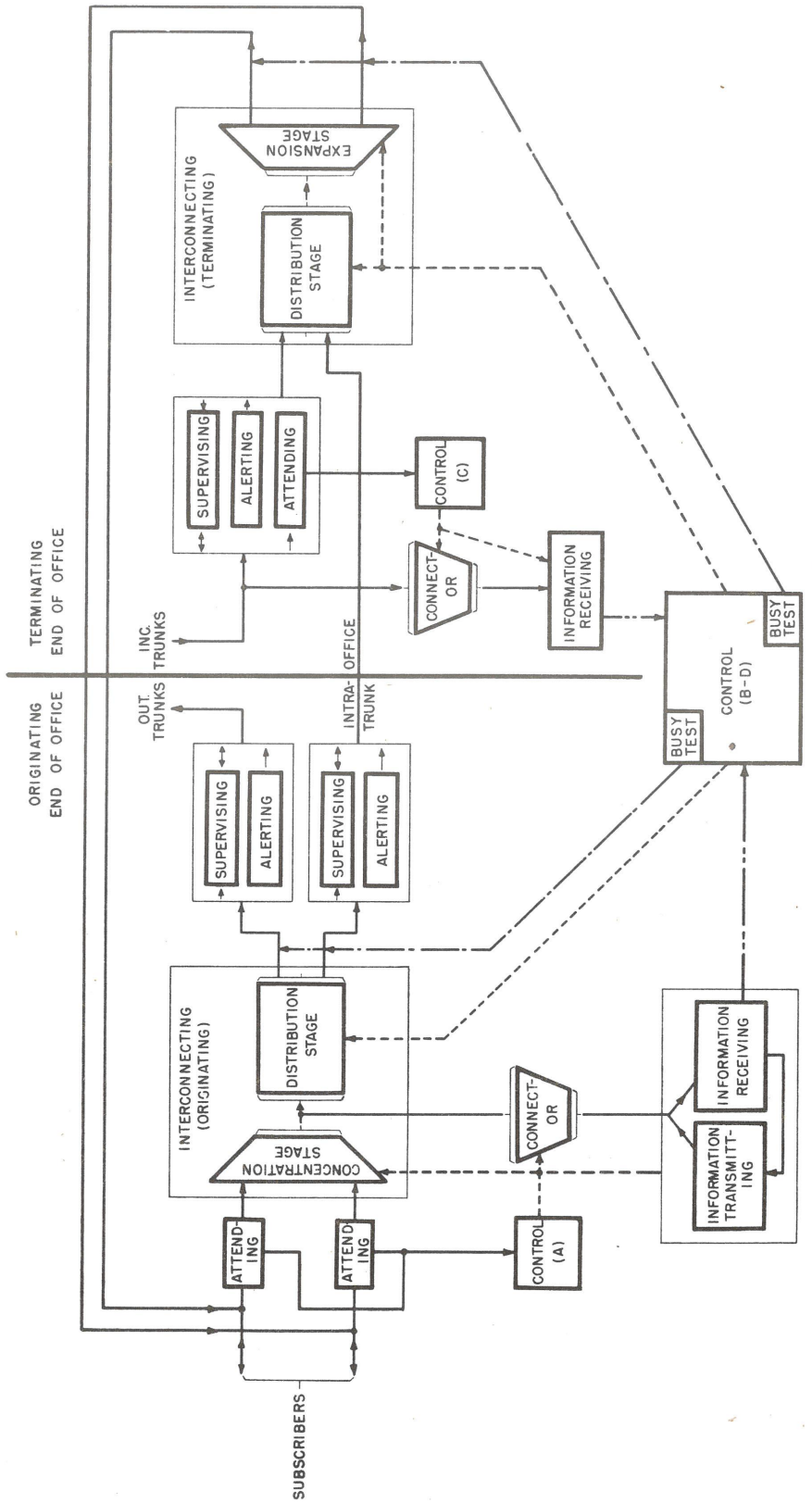


Figure 3-4 Automatic Type Office Showing Relationship of Switching Functions

3.3 A TYPICAL AUTOMATIC SWITCHING SYSTEM

Now that the basic switching functions have been enumerated and defined, it is well to fit them into a typical pattern for an automatic switching system. The example chosen for this purpose is not directly representative of any present-day system, but it serves to illustrate the principles involved in allocating the various functions with respect to each other.

The control principle utilized in this typical system is the type known as common control in which all interconnection control is grouped into one or more master circuit units. Although common control is a rather advanced type of control method, as will be discussed in Chapter 5, it offers the simplest transition from the manual type of office.

The block diagram of the typical switching system is shown on Figure 3-4. The interconnecting function or switching network is of the type where the office is split into originating and terminating halves with each subscriber's line multipled to both ends. The two networks can be considered as the two ends of the manual cord, although this is not an exact analogy. The originating network is divided into two major stages, the first of which serves to concentrate the line appearances down to a number of paths comparable to the number of peak simultaneous originating calls. This stage is followed by a distributing stage which gives access to all trunks connecting to the terminating end of the same or other offices. The terminating network is similar but inverted. Incoming and intra-office trunks connect to the input side of distributing and expansion stages which can carry a call to any subscriber's line.

At the input to the originating network of Figure 3-4 an attending circuit is associated with each subscriber's line. This circuit reacts to the signal from the subscriber that he is placing a call by marking itself as requiring service and notifying other switching circuits to respond in an appropriate manner. The output signal from the attending circuit to the control (A) function is equivalent to the lighting of the line lamp in the manual example (item 2, Figure 3-3).

The first major control action in an automatic switching office is to connect a calling subscriber's line to an information reception circuit. In this example, the information reception circuit is a separate entity with connecting means between it and any subscriber. The manner of connection is of some interest. As mentioned previously, the number of outputs of the concentration stage is of the same order of magnitude as the number of simultaneous expected conversations. Furthermore, since the distributing stage permits any link from the concentration stage to reach any output, the subscriber may be connected through the concentration stage before sending instructions to the signal reception circuit. Since the holding time of the information reception circuit is considerably less than that of the talking paths, it is unnecessary to provide an information receiving circuit per talking path, even at the output of the concentration stage. Therefore, some kind of connector is necessary and, for most economical operation, this connector should be between the concentration outputs and the information reception circuits, as shown on Figure 3-4.

The control means for this connection, shown as the control (A) block on Figure 3-4, responds to the signal from the attending circuit. Involved in the control operation is the finding of the calling line, location of an idle information reception circuit, and the setting up of a connection between them through the concentration switching stage and the connector. This corresponds to the response of the operator to the line lamp signal in manual systems, designated control action (A) in item 3 of Figure 3-3. The control circuit, which disconnects as soon as it has fulfilled its function, must operate very rapidly both to minimize service delays to the subscriber and for efficient operation, since the controller is a common circuit.

When the information reception circuit is connected to the subscriber's line, it usually returns a "ready" signal (dial tone) to him. The subscriber thereupon transmits his directions in whatever coded form the system requires (item 4, Figure 3-3). At the present time the information is usually in the form of dial pulses. The information reception circuit records the information and, when it is complete, connects itself to a control circuit shown as the control (B-D) block on Figure 3-4 and passes to it the control information. This action was unnecessary in the manual system since the operator fulfilled the functions of both information reception and control.

The first connection to be described in the automatic type office will be one in which the call is to another subscriber in the same central office. In the manual system of Figure 3-2, completion of the local connection after reception of the control information required but the single control operation of plugging the cord into the called line jack. This was listed as control action (D) in item 12 of Figure 3-3. However, in the automatic system of Figure 3-4, because of the split nature of the interconnection network it is desirable to set up the connection in two consecutive steps. The first control action, unnecessary in the manual system of Figure 3-2 for local completion calls, consists of setting up a connection through the originating switching network from the calling subscriber to an outlet path leading to the terminating switching network of the same office. This outlet path is generally called an intraoffice trunk. Since the connection through the concentration stage has already been established by the control (A) block, it is only necessary for the control means to continue the connection through the distribution network. This control action is comparable to item 5, control action B, of Figure 3-3, which described the method of setting up a manual connection to an outgoing trunk.

The next control action consists of establishing the connection from intraoffice trunk to called line through the terminating switching network. This, in turn, is comparable to control action (D) in the manual system, listed as item 12 in Figure 3-3. The means of performing the B and D control actions in the automatic system is shown on Figure 3-4 as a single functional block, control (B-D), although in certain systems it is more convenient to divide the (B) and (D) actions between two separate equipment units.

In addition to the primary function of establishing network paths, the control (B-D) block must also perform certain associated functions. The most important of the several functions of the block are listed below in order of occurrence.

1. Determine from the office code the group of output trunks required and the location of the trunk group at the output of the distributing stage of the originating switching network.

2. By means of the busy-test function, choose a particular idle trunk and also determine its specific location on the network. (For local completion calls, the location on both originating and terminating switching networks must be known.)

3. Establish a connection between the previously determined input to the distributing stage and the output trunk.

4. Determine from the line number code the location of the called line at the output of the expansion stage of the terminating switching network.

5. By means of the busy-test function, determine whether the called line is idle.

6. If the line is idle, establish a path from the known input to the terminating distributing network to the called line.

7. If it is impossible to set up the complete connection either because of line, trunks or paths busy, establish a condition which will return an appropriate signal to the calling subscriber.

The control function in general, particularly if it is of the centralized type illustrated, should be as rapid-acting as possible to reduce the number of units required.

When the connection has been established, the information reception and control circuits drop off, becoming available for other calls, and the alerting function takes over. Since the call is to a subscriber where ringing is employed, the circuits must include means for applying the ringing current and cutting it off when the subscriber answers. This is similar to the manual function of item 14, in the table of Figure 3-3. In Figure 3-4 the alerting function is shown associated with the supervising function in the intraoffice link between originating and terminating networks. This grouping of circuits associated with the talking path is common, and, in the position shown on Figure 3-4, would be called a trunk circuit. When the alerting signal is ringing current, a common source supplies the individual alerting circuits of the trunks.

Control over the established connection is exercised by the supervising function, which is located, as mentioned before, in the concentrated region of the switching network between the originating and terminating stages. Its precise location depends largely upon the particular system involved. For example, in Figure 3-4, an alternate location might be between a distribution stage and the concentration or expansion stages.

In general, the connection holds to the supervisory circuit and automatically releases when either or both subscribers hang up. This corresponds to the lighting of supervisory lamps and the release of the connection by the operator in the manual system (items 15 and 16 in Figure 3-3). With automatic release there is no action directly comparable to the control (E) action of item 16, Figure 3-3. However, with certain types of systems, it is necessary for the supervisory circuit to call into action a control circuit to release the connection.

If the call were to another office, the procedure would be the same as that described for the intraoffice call up to the point where the information reception circuit connects to the control (B-D) circuit. The control circuit, in establishing the connection from calling line to outgoing trunk, exercises only functions 1, 2, 3, and 7 of the group listed on page 13. This control action corresponds to action (B), item 5, Figure 3-3, in the manual interoffice connection. The subsequent events in the interoffice call can best be understood by assuming that the terminating equipment shown on Figure 3-4 is located at the distant office and that the incoming trunk connects back to the outgoing trunk path. In effect, the originating and terminating ends of Figure 3-4 represent two different offices.

When the originating connection has been established to the outgoing trunk, an alerting function must notify the distant office that a call is being made. An attending function in the terminating office responds by causing the control (C) block to set up a connection from the incoming trunk to the information receiving block. At the same time, the information transmitting function at the originating office is associated with the outgoing trunk and can send control information to the distant end when it receives a ready signal. These events correspond to items 7 through 11 of Figure 3-3.

The information transmitting function, although shown associated with the information receiving function on Figure 3-4, may be a separate and independent entity. In the position shown it may receive the information to be transmitted either directly from the information reception circuit or indirectly from the control (B-D) circuit. If the information transmission circuit were separate, it might be associated with the outgoing trunk by means of a connector and receive information from the control block. The alerting function, although shown in the outgoing trunk path, might instead be grouped with the information transmission function.

When the information receiving function has recorded the called line number, it connects to the control (B-D) function located in the distant office. The latter circuit interprets the called number and establishes the connection through the network from incoming trunk to line. This involves subfunctions 4, 5, 6, and 7 of the group on page 13. The action is equivalent to item 12, control action (D), in the manual case of Figure 3-3. Thereafter the information transmitting and receiving functions and the control function all drop off the established connecting path.

The alerting function associated with the incoming trunk transmits a ringing signal to the called subscriber and, when the call is answered, the supervising function maintains control of the connection. This is the same as in the case of the intraoffice call.

3.4 CONCLUSION

The primary purpose of this chapter has been to outline the basic functions of any switching system from the central office point of view, and then to relate these functions in a theoretical but typical central office. No attempt has been made to go beyond a broad statement of the functions nor to list in any detail the requirements or techniques of circuits to perform the functions. For several of the functions it is not necessary at the present time to go beyond what has been already said. However, to gain some comprehension of the various types of systems, the nature of switching networks and the associated control means must be explored more thoroughly. These two subjects will be discussed in the next two chapters. In the latter part of the course, the technique for designing circuits to fulfill switching functions will be taken up in detail.

CHAPTER 4

SWITCHING SYSTEM PRINCIPLES, PART II—SWITCHING NETWORKS

4.1 INTRODUCTION

The interconnecting function is the framework of any switching system and its form determines to a large extent the nature of a particular system. The individual switching elements and the manner in which they are associated affect the interrelation of the other basic and subsidiary functions, and, perhaps of most importance, react upon the type of control. The inverse relationship, as pointed out previously, is also true.

The purpose of the interconnecting function, as defined in Chapter 3, is to provide the means for establishing talking paths between any two subscribers or between any subscriber and the incoming or outgoing trunks of the office. Traditionally this function has been performed by wire and electromagnetic or electromechanical switch networks which generally take the over-all form shown in Figure 4-1. This generalized form is subject to two principal modifications which depend upon the access capabilities of the switching elements used, and upon whether connections can be set up in two directions through the switching network or only in one. If access capability is large, it is possible to absorb either partially or wholly the distribution stages into the concentration and expansion stages; if the switching networks are bidirectional, the terminating network may be folded over and superimposed either partially or wholly upon the originating network. This will be taken up more fully toward the end of this chapter.

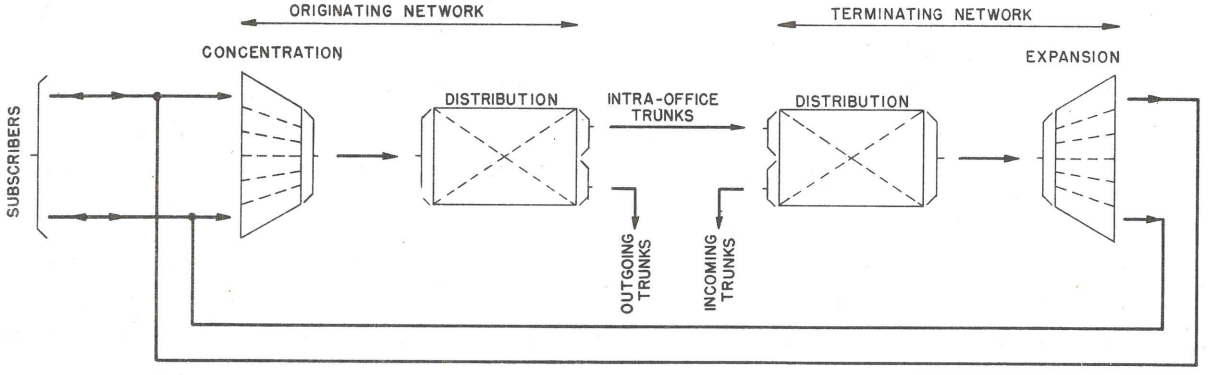


Figure 4-1 Standard Form of Interconnecting Network

LINK

The major part of this chapter will be devoted to a discussion of the techniques of utilizing electromagnetic switching devices with relatively small access capabilities for networks suitable for telephone switching. However, as an introduction to the general subject of switching networks, some alternative methods will be mentioned.

Some thought on the philosophical implications of the electromechanical switch and wire network will indicate these alternative methods of switching. Fundamentally, the wire and electromechanical switch network provides a multiplicity of individual paths through the office over which conversations can take place. Many separate conversations can go on during the same time period, with each one occupying the same audio frequency band. This can conveniently be called the path separation method of switching. This general method can be carried out by means other than wire and switches. For example, a system may employ modulated light beams as a means of setting up the individual talking paths.

Recognition of frequency and time as factors in the switching problem introduces the possibility of two other fundamentally different methods of switching. If simultaneous conversations are set up in different frequency bands, with means provided at each subscriber line and trunk terminal for recognizing assigned frequencies, the switching system is based on the principle of frequency separation. This involves elements of carrier transmission technique with provision of means whereby the control circuit can assign transmitting and receiving frequencies to appropriate points in the system on a call to call basis. With this system the transmission medium, metallic or otherwise, could well be common to the entire office and individual calls would be simultaneous in time, but separated in frequency bands.

A third method of performing the switching or interconnection function is based on the principle of time division multiplex. Each channel is assigned a particular time slot, in effect, in a repeating cycle. The audio frequencies of each call are converted to modulated pulses at the cyclic rate established for the system, and gating means at the terminals, under the direction of control circuits, permit only the pulses of the assigned channel to reach the associated terminals. The staggering in time of the minute elements into which each call is split provides the differentiation among several simultaneous conversations. Since the transmission medium can be common to the office and all frequencies fall in the same band, time separation is an appropriate name for this switching principle.

Thus, by varying one at a time the three factors of physical path, frequency band, and time, three fundamentally different techniques of performing the interconnecting function are evolved. Of these, frequency and time separation methods are just beginning to be explored. Therefore, except for this brief mention, this chapter will be concerned with path separation methods employing conventional switches.

4.2 BASIC SWITCH TYPES

The basic switch unit used for interconnection purposes consists of a single input (which may include several individual but associated leads) that connects by means of the mechanism of the switch to any one of several outputs. The physical motion required to connect the input to a particular output may be imparted in a variety of ways. Notable amongst them being simple electromagnetic closure, electromagnetic stepping or ratchet action, and power drive with or without a clutch. There are no mechanical switches in common use at the present time in which different individual inputs can connect to the same physical output point in space; therefore to obtain a multi-input switch connecting to a common group of outputs requires the multipling of the outputs of several switch units. Since it is rarely economical to provide at any point in a switching system only a single input feeding into a group of outputs, switch units almost invariably are multipled together in this fashion.

The number of outputs of a particular switch unit is limited by several factors. Among these are construction difficulties, physical size, and time required to move to a particular output terminal in a set. Where stepping action is involved and a base-10 system of notation is utilized in switch control, the output access is generally limited to ten terminals. Another very important factor is that, of all outputs of a switch unit, only one can be used at a given time. Therefore, what might be called "crosspoint efficiency" sets some economic limit to the number of output terminals per switch unit.

A good example of the basic switch unit is the simple 10-point rotary switch shown schematically in Figure 4-2A. A single input can connect to any one of ten outputs by stepping around the arc. A convenient symbol, which will be used throughout the text to represent this type of device, appears in Figure 4-2B. It should be noted that in this, as in other switch structures, several arcs together with the same number of mechanically linked wipers can be provided so that the switch can carry more than one lead. A physical switch, representative of this type, is shown on Figure 4-3.

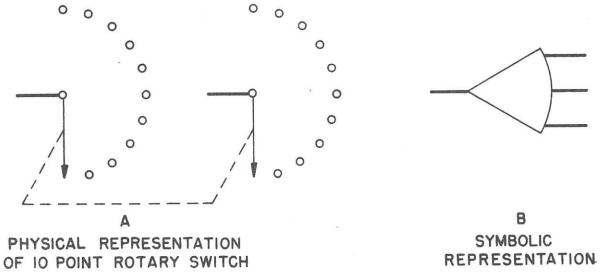


Figure 4-2 Representations of Single Input, Multi-output Switching Device

Commercial switches used for telephone switching are usually designed for ease in multipling the output terminals of individual units.. Several units so multipled

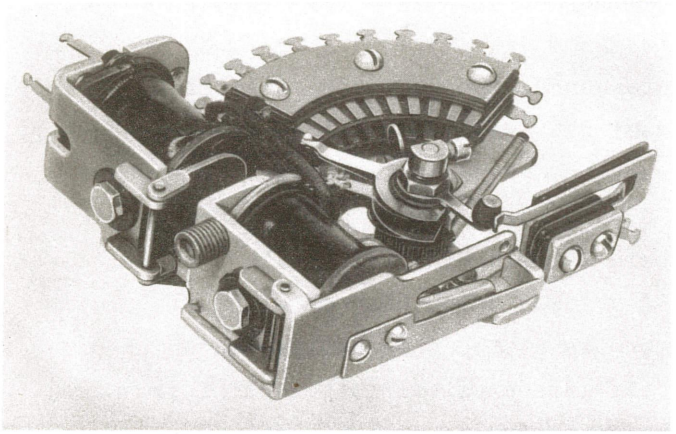


Figure 4-3 The 204-Type Selector Switch

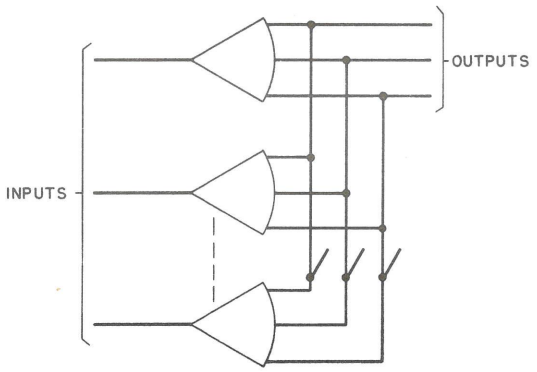


Figure 4-4 Switch Unit
Multipled Outputs

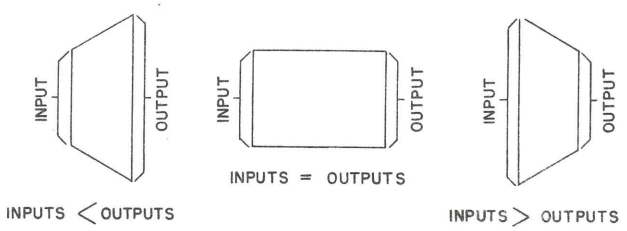


Figure 4-5 General Symbols for
Switch Networks

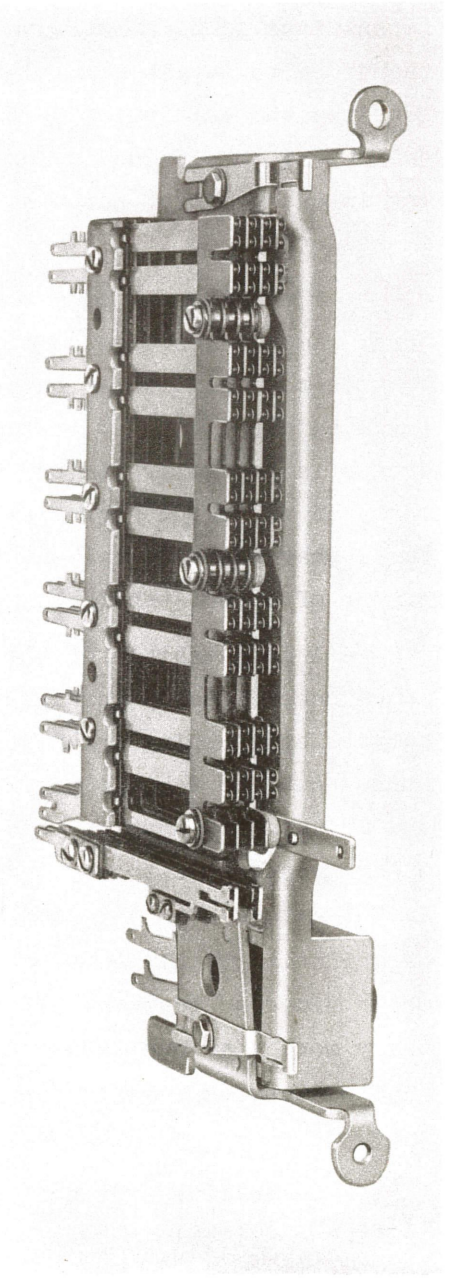


Figure 4-6A The Crossbar
Switch

are shown symbolically on Figure 4-4, and general symbols representing such aggregations of switch units with varying balance between inputs and outputs appear on Figure 4-5. These latter symbols can also represent whole networks. A good example of such an aggregation of switch units is the crossbar switch. An individual vertical unit, shown on Figure 4-6A, provides for connecting one input by electromagnetic closure to any one of ten outputs; the complete switch with ten vertical units mounted together is shown on Figure 4-6B. The structure permits easy multipling of the outputs of the vertical units across the back of the switch. This type of switch is bidirectional in that either side can be considered the input side. The switch is also provided in a larger size with twenty vertical units.

Another example of multipled switch units, this time with very high access, is the panel switching frame shown on Figure 4-7. Here an individual input is a vertical brush-carrying rod with access to five banks of terminals, each bank 100 terminals high. The output multiple is built into the frame in the form of punched metallic strips which extend across the width of the frame. As many as 60 brush rods connectable to the same output multiple can be accommodated on one frame. A motor drive with individual clutch per brush rod is employed by the panel frame to make selections. The design permits an initial selection of a group of terminals and then selection within a group.

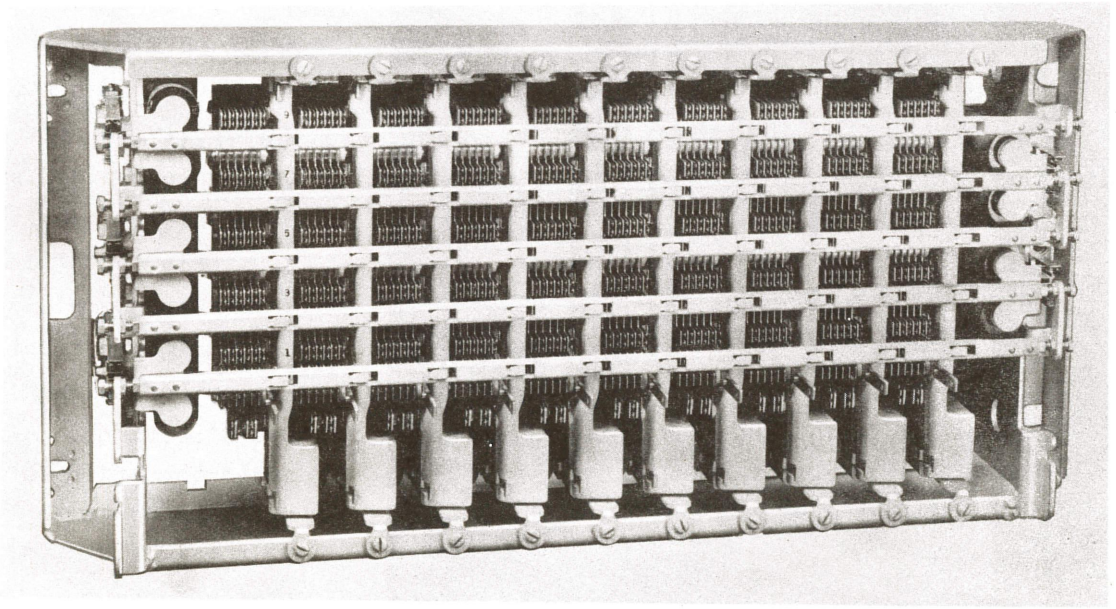


Figure 4-6B The Crossbar Switch

When the basic switch unit is restricted in the number of output terminals, say to ten, it frequently is necessary to increase the output access per input. There are two ways of doing this. The most obvious, that of multipling the inputs of several switch units, is indicated on Figure 4-8. This method implies that the control means can determine and select the particular unit required to reach the desired group of outputs. A second method of extending access is to group the switch units in two stages as shown in Figure 4-9. With this arrangement, the first stage switch selects an output switch and the second switch then selects within its group of outputs.

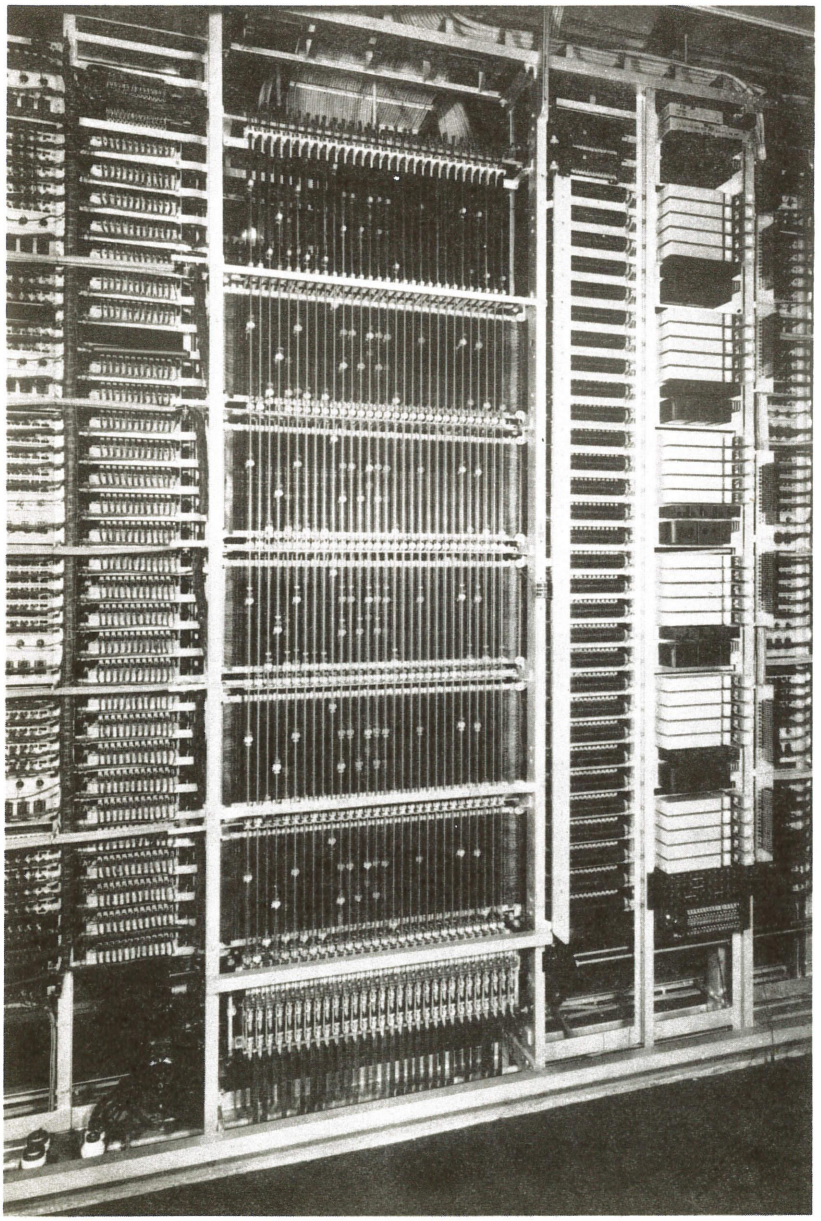


Figure 4-7 Panel Switching Frame

Although the two-stage method apparently requires one more switch unit than the multipled input arrangement, in practice it is possible to build economical switches with a double motion which perform the two stage selections with a single input brush structure. An example of this is the step-by-step switch, shown on Figure 4-10, in which the brush steps vertically to select one of ten levels and steps horizontally over ten terminals in the level. This switch employs electromagnetic ratchet action for moving in the two directions. In order to obtain sufficient inputs to load up the 100 outputs, the switches are usually provided in groups with outputs multipled.

4.3 CONCENTRATION STAGE OF SWITCHING NETWORK

With the preceding section as background, it is now possible to discuss the manner in which units are combined to form an over-all switching network. A network of the general form of Figure 4-1 has been established as optimum for central office purposes. In developing the switch interconnections to produce this type of network, the simplest point at which to begin is the concentration stage.

The problem at the concentration stage is to connect from a large number of subscriber lines to a limited number of paths which in turn are capable of connecting through the remainder of the network to any desired terminating point. The number of these concentrated paths that must be provided is a direct function of the amount of originating traffic generated by the subscribers, and in practice it it always substantially less than half the number of subscriber lines. Since all outlet paths will have eventual access to all outputs of the office, it makes no difference to which path any subscriber is connected.

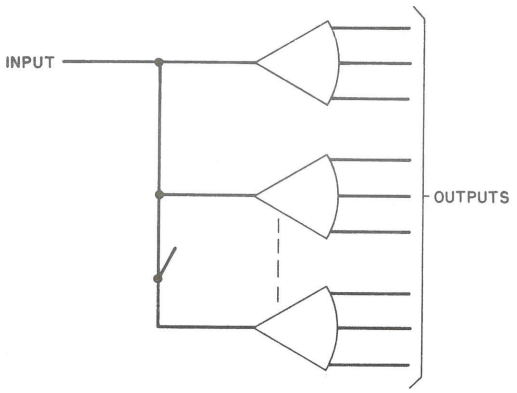


Figure 4-8 Switch Units With Multipled Inputs to Extend Output Access

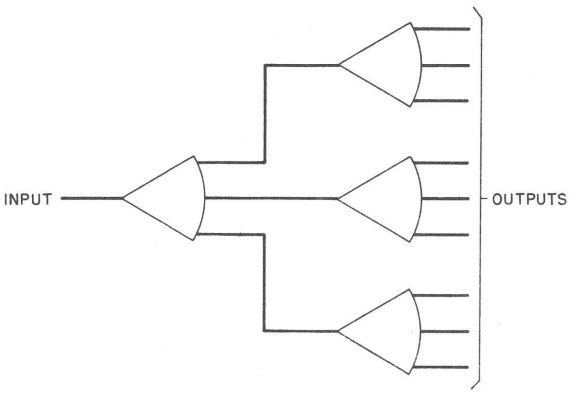


Figure 4-9 Switch Units in Two Stages to Extend Output Access

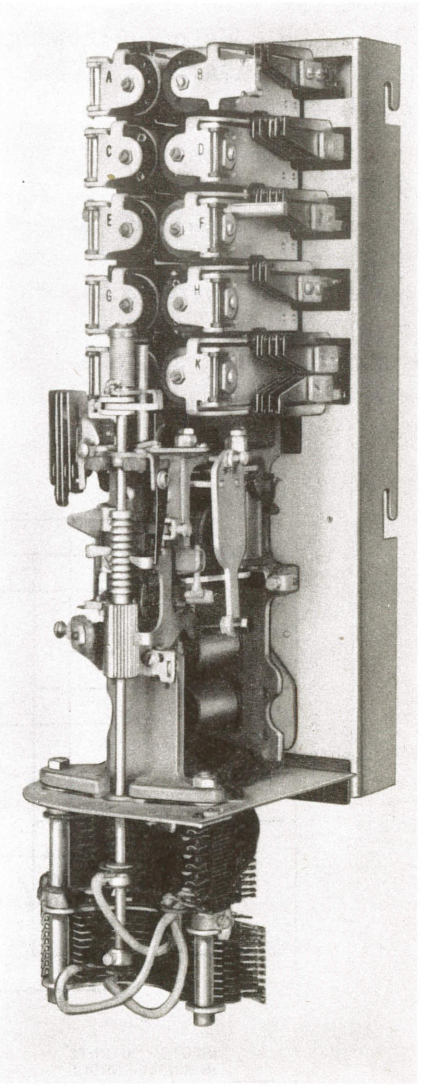


Figure 4-10 Step-by-Step Selector Switch

The most straightforward method of handling this situation is to provide each subscriber line with an individual switch as shown on Figure 4-11A. The outputs of groups of switches are multipled and sufficient switches are provided in one group to load up the output paths adequately. In operating, an input hunts over output terminals until an idle one is located. Since there are more inputs than outputs, it is clear that a high level of traffic can produce more calls than there are paths to handle them and blocking will occur. This, as will be seen, is a recurrent situation in switching. The ratio of inputs to outputs is usually so adjusted that on the average during the busy hour no more than one call in one hundred or, in some cases, one call in a thousand will be blocked because of access limitations. It is worth noting here that the larger the group of common paths, the more efficient is the use of them, as is brought out more fully in the Probability and Statistics Course.

The drawback with the scheme of Figure 4-11A is that one switch per input is required, yet no more switches than there are outputs can ever complete connection at one time. This suggests reversing the switches so that they face toward the line side and providing them in quantity equal to the number of output paths. This method, known generally as the line finder principle, is illustrated in Figure 4-12A. In operation, when a line originates, controls must actuate one switch to find and connect to the line.

On the basis that the number of switch terminals per switch can be chosen at will, the line switch method, in the form shown on Figure 4-11A and utilizing what might be called forward facing switches, requires switches equal in number to the quantity of subscribers S, each switch with output terminals equal in number to the quantity of total output paths P. The total number of connecting points, or crosspoints, is S x P. The line finder principle on the other hand, using backward facing switches, reverses the numbers of switches and terminals per switch required, but still requires crosspoints equal in number to S x P.

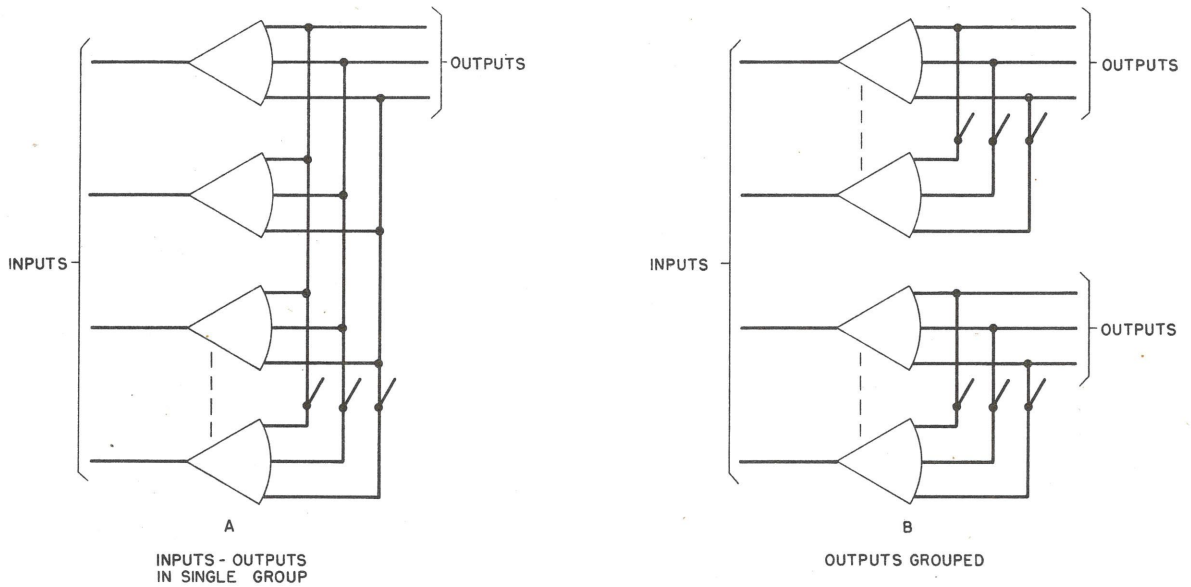


Figure 4-11 Concentration—Line Switch Principle

These quantities can be modified considerably by employing the principle of grouping, that is, giving fractions of subscribers, say S/X, sole access to fractions of output paths, say P/X. This, in accordance with the principle of efficiency being proportional to group size, reduces the efficiency of use of the output paths; but, if these groups can be kept reasonably large, considerable savings in equipment can be realized. Grouping applied to line switch and line finder applications is shown in Figures 4-11B and 4-12B.

As a specific example of these principles, assume that the traffic originated by 1000 subscriber lines can be handled by 100 output paths, and any output is satisfactory for use by any input. The chart below gives the equipment quantities required by line switch and line finder methods, with and without grouping. The dividing factor for grouping is taken as 10. It is assumed that no loss of efficiency results when access of 1000 lines to 100 paths is reduced to grouped accesses of 100 lines to 10 paths. This assumption is not strictly true, and in practice the total number of output paths would have to be increased somewhat above 100 to give the same grade of service as is obtainable in the single group.

Situation	Number of Groups	Number of Switches per Group	Total Number of Switches	Terminals per Switch	Total Number of Terminals
Line Switch, No Grouping	1	1000	1000	100	100,000
Line Switch, Grouping	10	100	1000	10	10,000
Line Finder, No Grouping	1	100	100	1000	100,000
Line Finder, Grouping	10	10	100	100	10,000

From this table the optimum arrangement appears to be the line finder with grouping. Factors that must be considered in arriving at a practicable arrangement are that a 1000-terminal switch is probably not practical, and that the number of terminals, within fairly broad limits, is not the controlling element in switch cost.

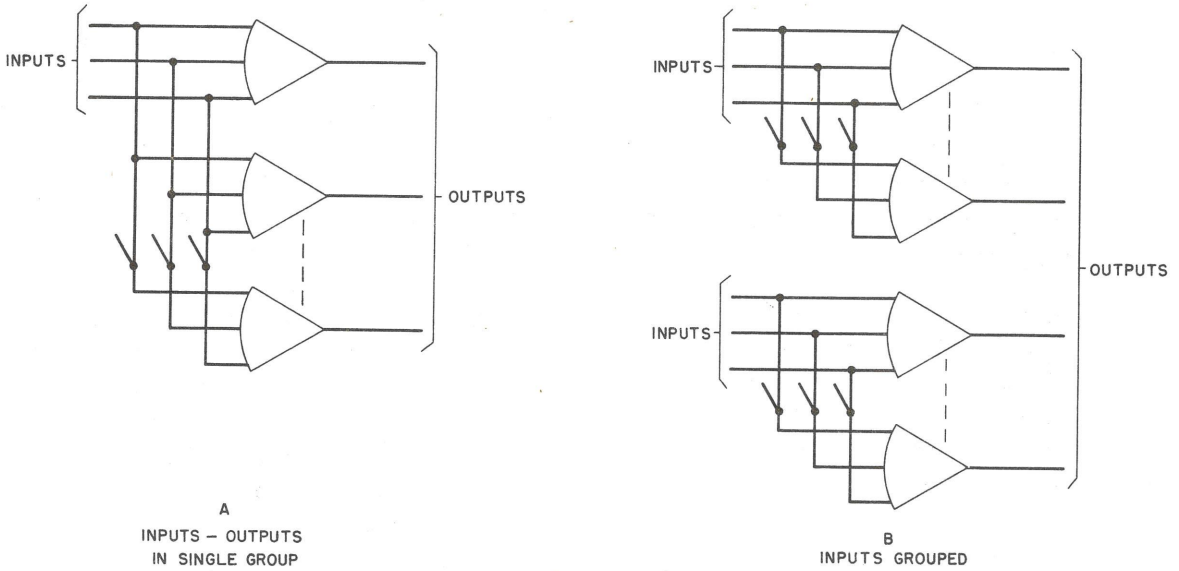


Figure 4-12 Concentration—Line Finder Principle

There are other methods of handling the concentration problem in switching. However, these are of a more advanced nature and will be discussed later.

4.4 EXPANSION STAGE OF SWITCHING NETWORK

In continuing the development of the over-all switching network, the next logical step is to discuss the expansion stage. It will be found that the distributing stages fall naturally into place during this development.

There are two main lines along which the expansion network can grow and which depend upon the type of control to which the over-all network is subject. These types of control, which are discussed in the next chapter, may be called progressive and common. Progressive control implies that the selection of a path through the network to a desired output advances stage by stage with no foreknowledge of conditions ahead. Common control implies that the two terminal points are first identified and that the network as a whole is then examined for possible paths between them. The progressive type of network is discussed first. However, as an introduction to the subject, an elementary form of a combined concentration-expansion network which is of general usefulness will be mentioned.

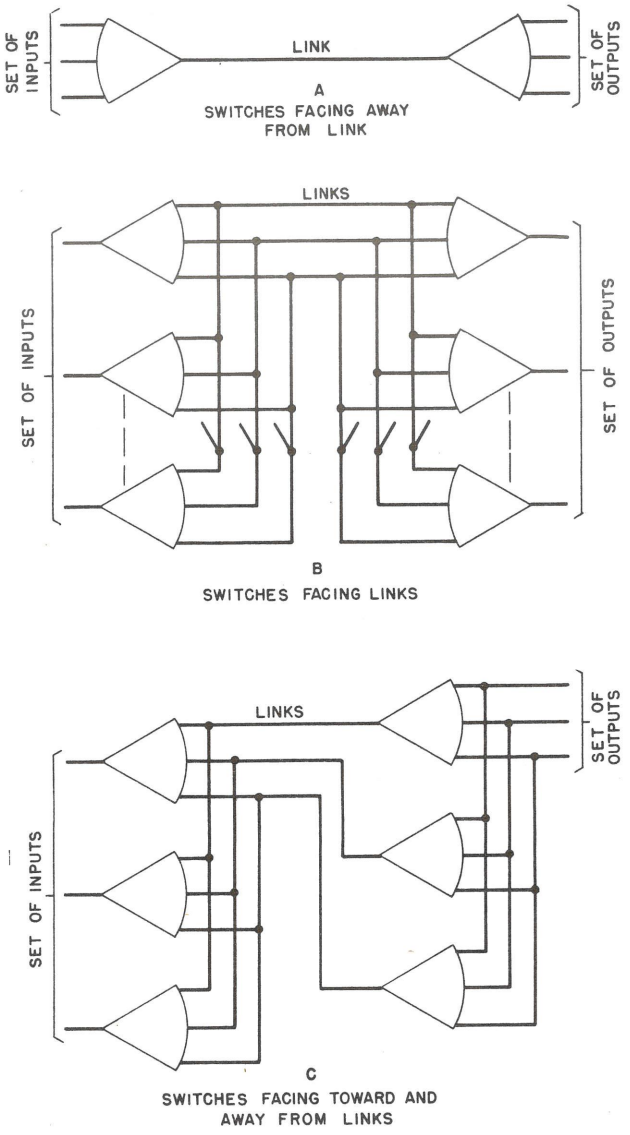


Figure 4-13 The Link Principle

Assume a situation in which a group of inputs are concentrated down to one output path in a manner similar to that performed by one of the switches in Figure 4-12A. The output path in turn must be able to reach a multiplicity of output terminals. This can be accomplished by placing a forward facing switch at the other end of the output path as shown in Figure 4-13A. The path connecting the two switches is known as a link, which may, in general, be defined as a connecting path between two sets of multiple terminals. Other switch configuations utilizing links as connecting paths are shown in Figures 4-13B and 4-13C. It can be seen in these figures that each link has access to several points at each end. The use of links at various stages within switching networks is well-nigh universal since it permits the proportioning of equipment to traffic with only sufficient links being provided to accommodate the expected maximum number of simultaneous calls.

In developing the expansion stage of a switching network of the progressive type, assume first a simplified

situation in which only one central office is involved and there are a limited number of subscribers. By definition, the paths to which subscriber lines are concentrated are links, and therefore an input to the expansion stage is a link. If the number of subscribers is ten and the individual switch access is ten, the expansion stage would appear as in Figure 4-14. Links are furnished in quantity sufficient to handle the traffic. This configuration is similar to that of Figure 4-11A except for the ratio between number of inputs and outputs.

If there are more than ten subscribers and, therefore, additional outputs are required, either switch access must be increased or more switching stages supplied since every input link must have access to all outputs. It is convenient for the moment to restrict switch access to ten in order to illustrate the principles involved. The ten-point switch is also desirable if switch control is on a decimal basis with each stage corresponding to a digit in a line number.

Increased access can, then be accomplished by the two-stage tree-type network of Figure 4-9 associated with each link. Each output is multipled to a corresponding terminal on the networks of the other links. Access is thereby raised from 10 to 100 with a total of 11 switches per link. Connection to a particular output is accomplished by a successive stage-by-stage selection process. However, this method by itself is very inefficient since only two of the eleven switches can be utilized simultaneously on a connection. Furthermore, the efficiency becomes very rapidly worse as more stages are added. In order to improve efficiency, it would be desirable to give other links access to the group of second-stage switches. This can be accomplished by the multipling arrangement of Figure 4-15, in which the outputs of several first-stage switches are multipled together to connect to the second-stage switches. By this means several simultaneous connections can be made through the same set of second-stage switches. This example, extended to provide for several inputs groups, each connecting to its own set of output switches which in turn are placed in separate groups, is shown on Figure 4-16. This network has the limitation that only one connection can be made at a time from one input group into a particular output group. In other words, one connection into an output group of ten from a particular input group blocks the other nine terminals of the input group from service into the same output group. When traffic must be handled on a no-delay basis (no waiting for a path to become

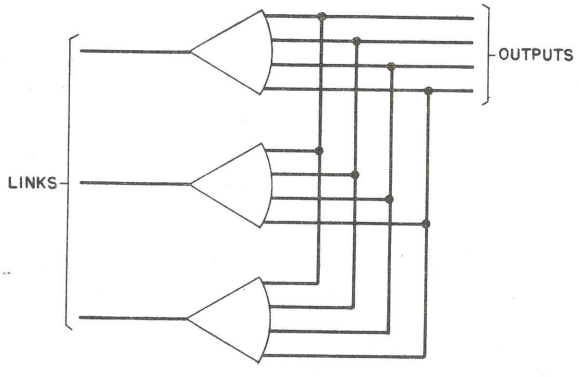


Figure 4-14 Expansion From Links to Output

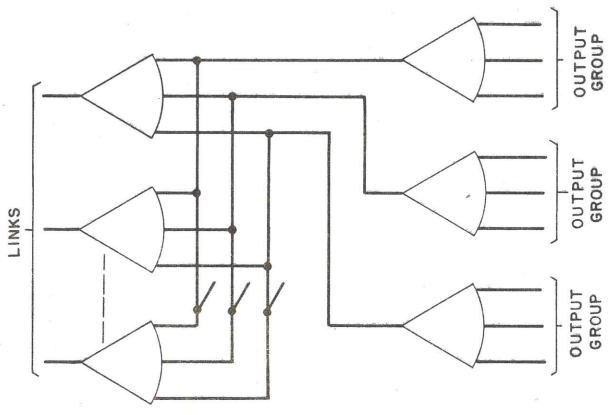


Figure 4-15 Multipled Inputs to Second-Stage Switches

idle), as is generally true in switching through the central office internal network, the probability of blocking in the situation described is too high for practicability. Although traffic on the average may distribute itself evenly over all the output groups, short time deviations will load output groups unequally.

The answer in this particular case lies in switch design rather than network design. The type of switch that would normally be used in this situation incorporates two switching stages in its structure and performs the selecting action by a double motion. Functionally, it is equivalent to Figure 4-9. The additional cost of the second-stage elements is small compared to the basic first-stage cost, so that it is economical to provide this two-stage switch per link, and thus have direct access to 100 outputs (or whatever the switch capacity might happen to be).

However, if output access must be of a higher order, say 1000, 3 tree-type stages of ten-point switches are required. This would require 111 ten-point switches per link of which only 3 can be used simultaneously. This clearly necessitates some modification for efficiency.

As in the previous case, the final two stages in each branch of the three-stage network can be combined into economical two-stage switch units with output access of 100. These single-switch output units are conventionally known as connector switches. Use of the double-stage connector switches in effect reduces the three-stage problem to one of two stages. Assuming that further modification of switch structure becomes impractical and since the multipling arrangement of Figure 4-16 is still not adequate between first and second-stage switches for the reasons stated before, some other technique must be found.

The answer lies in the insertion of another switching stage between the input switches and the second-stage connector switches. The purpose of the intermediate additional stage is to permit each first-stage output to connect to any one of a common group of connector switches per hundred lines instead of being permanently connected to a particular connector switch.

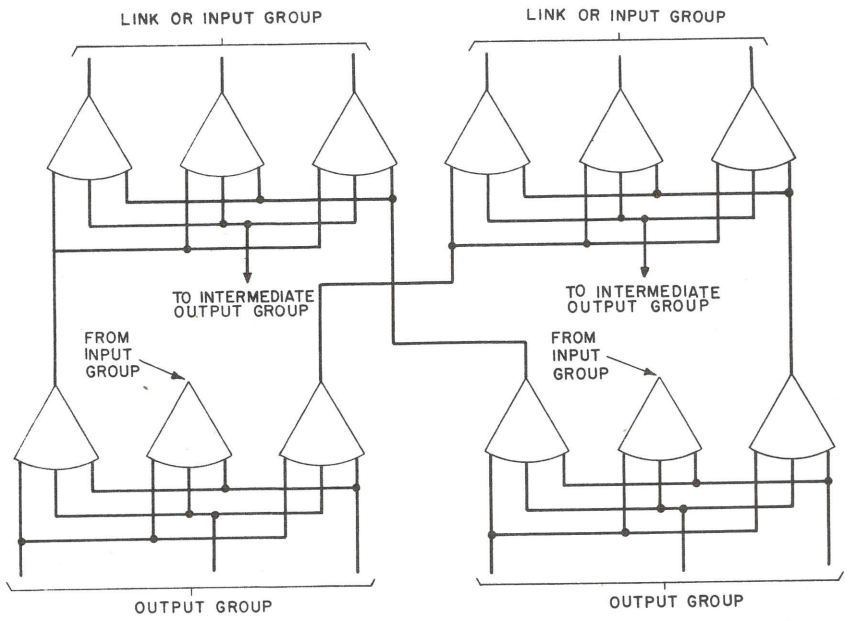


Figure 4-16 Multipled Groups of First-Stage Switches Connecting to Groups of Output Switches

As will be seen, the primary implication of this arrangement is that the number of connector switches per output group can be held down to the quantity required by traffic into each group. Since total input traffic will tend to divide equally among the several output groups, the total required number of connector switches should be approximately the same as the number of input links. Thus, the

selecting stages ahead of the final connector stage will have roughly the same number of outputs and inputs and will perform a distributing function in which a call from an input link will be guided to a connector in the desired output group. The expansion functions will then be confined to the connector stage.

4.5 DISTRIBUTION STAGE OF PROGRESSIVE SWITCHING NETWORK

The general plan embodying the additional switching stage is shown on Figure 4-17. Each output of a first selecting stage switch connects to an

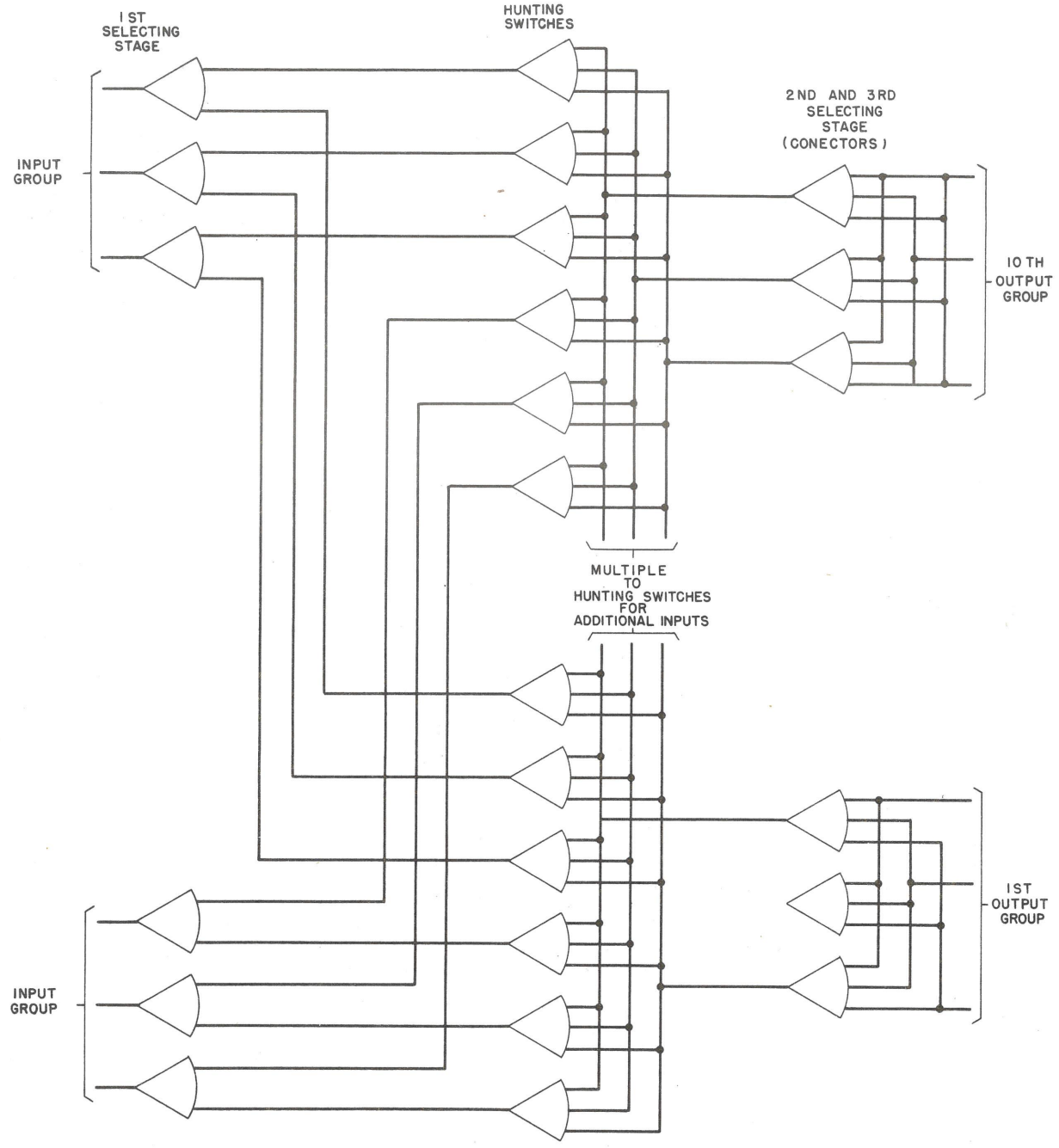


Figure 4-17 Hunting Switches Between Selector Stages

individual hunting switch which is capable of stepping to any idle terminal. Each output terminal of the hunting switch in turn connects to one of a group of identical connector stage switches, the outputs of all of which are multipled so that any switch can connect to any output in the group. The hunting switch outputs (inputs to a group of connectors) are multipled to the corresponding hunting switches of other first-stage switches. By this means a particular selection on any first-stage switch gives access through the hunting switches to a group of connector switches, any one of which can connect to the desired output. The

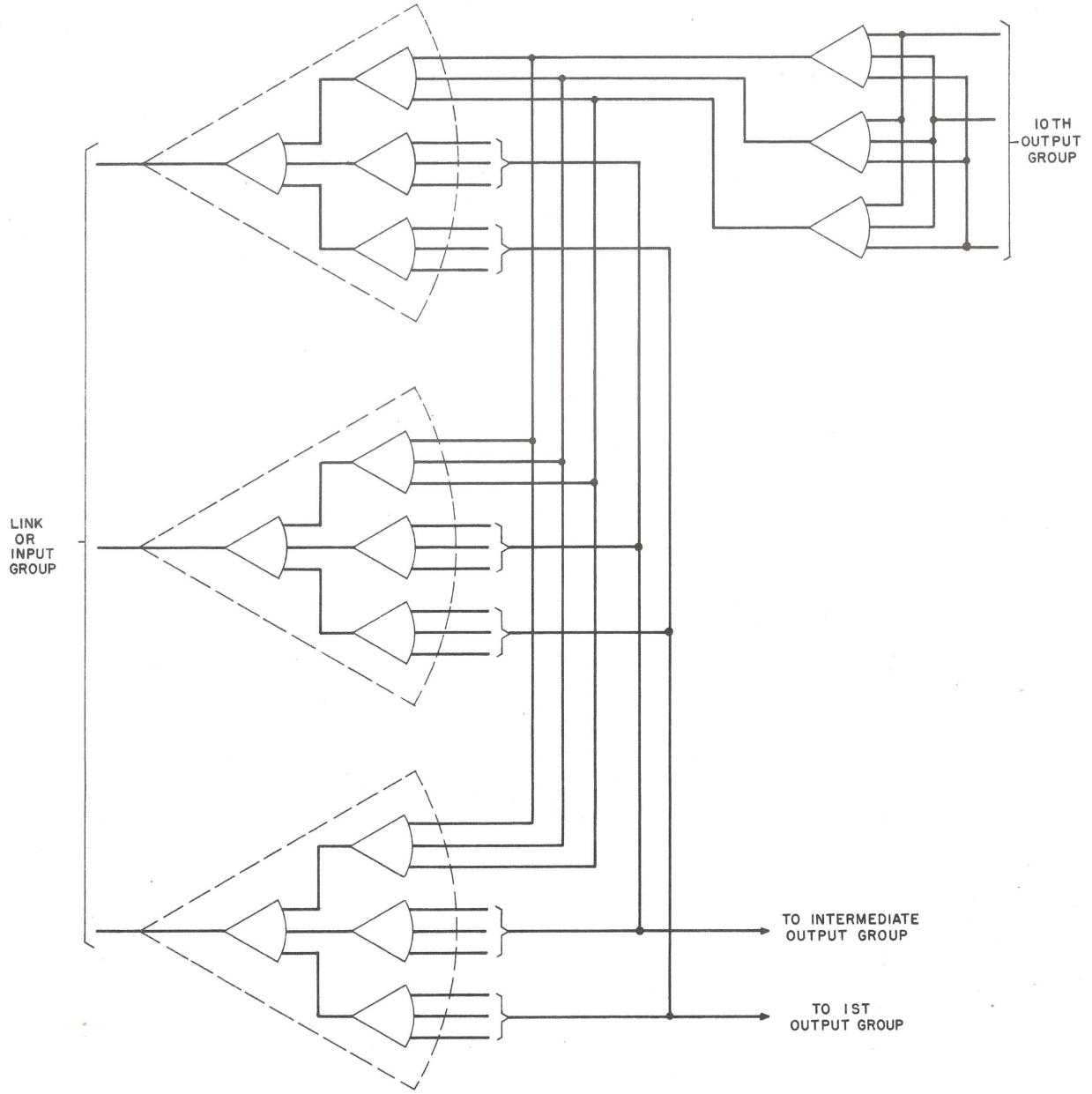


Figure 4-18 Relating Hunting Switches With Associated First-Selector Switch

number of connector switches per group can easily be proportioned to the expected maximum traffic into the group. For example, assume that 100 links must connect to 1000 outputs (subscribers), the latter divided into 10 groups of 100, and that the maximum expected simultaneous traffic to any one group of 100 subscribers is 10 calls. Using the hunting arrangement of Figure 4-17, this requires 100 connector switches, whereas provision of 10 separate connector switches per first selector would require a total of 1000 connector switches. Although there is a rather large saving in number of connectors when the hunting arrangement is employed, the gain is apparently counterbalanced by the quantity of hunting switches (10 per first selector, total 1000) that must be supplied. However, this disadvantage can, in turn, be largely nullified by the previously mentioned double-stage construction of the first selecting switches which makes the additional cost of the hunting stages negligible in comparison to the cost of connector switches, each of which, it must be remembered, is equivalent to eleven ten-point switches.

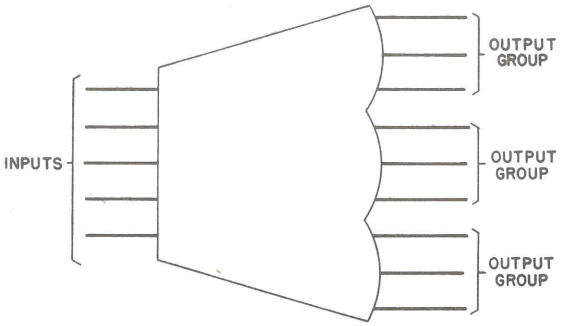


Figure 4-19 Symbol for Select and Hunt Stage

Figure 4-18 is a redrawing of three input switches of Figure 4-17 to show each first-stage selector switch incorporating its own group of hunting switches. Since, for this example, 100 first-stage switches are necessary, the total number of double-stage switches required, including the connectors, is 200.*

The use of hunting stages provides great flexibility in adjusting the quantity of equipment to meet required traffic conditions. Outputs can be placed as desired on the hunting stages up to switch capacity (and beyond, as will be discussed in the next section). For a given output group size, inputs can be added, as indicated on Figure 4-17 up to the desired loading. In this way the over-all output-input ratio of the distribution stages can be adjusted as required and the balance among the various output groups can be controlled.

A group of multipled selector switches with their associated hunting switches can conveniently be represented by the symbol of Figure 4-19 (compare with the first select and hunt stages of Figure 4-18). All inputs have access to the various output groups and to the individual outputs therein.

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*It will be of interest in a later section to note that, for this particular example of 100 links connecting to 1000 outputs in a progressive type network with hunting, the equivalent of 2200 ten-point switches is required.

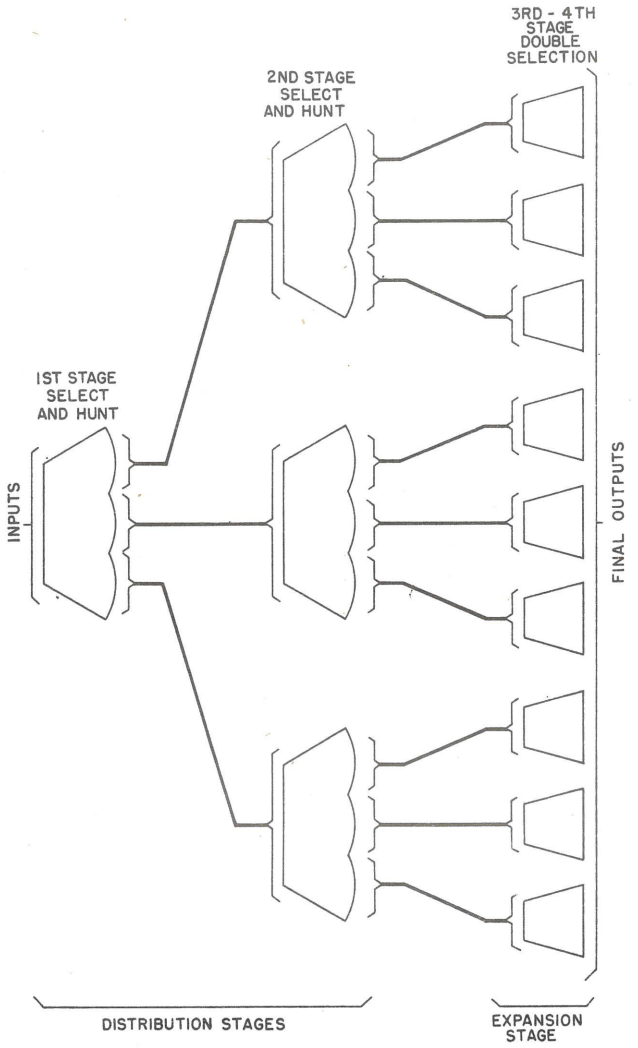


Figure 4-20 Progressive Switching Network—Four Stages

A network of four stages, using the select and hunt principle, is represented by Figure 4-20. Hunting is employed after each of the first two selecting stages, but is not desirable between the third and fourth. Any input looking into the network sees ahead of it a tree-type structure with four successive branching points which ultimately carry the connection to any one of 10,000 outputs.

With a large scale multi-stage distribution network of the type shown on Figure 4-20, it is difficult, without modification of the network, to provide as many intermediate paths between the stages as there are input or output paths for the network. If 1000 connector switches were required in the network of Figure 4-20, approximately 1000 first-stage input and output paths would be necessary for efficient distribution. One thousand first-stage outputs divided equally among the ten selectable levels requires 100 outputs per level. The small capacity switches generally used in this type of network cannot accommodate this many outputs. However, the difficulty can be resolved by breaking the first-stage switches down into small enough subgroups so that the outputs required per subgroup are within switch capabilities. The switch stages are then interconnected in the manner exemplified by Figure 4-21. In this example only the first-stage switches are subgrouped, but the plan can be carried further by subgrouping of second-stage switches if the number of outputs makes this necessary. By these means, the ratio of stage inputs to outputs can be adjusted to any value so that the first and second stages constitute a pure distribution network.

The originating distribution network is very similar to the terminating distribution network. The primary difference is that the outputs of the former network are trunk groups to various terminating offices (including the home office), whereas the outputs of the latter are groups of links feeding into the expansion stages. The trunk groups are likely to be of widely varying sizes depending upon the traffic to the different offices; in general, the link groups will be comparable to each other in size. Therefore the network balance at the originating

end may not be as symmetrical in appearance as at the terminating end, but the general effect will be similar. The number of stages in the originating network depends directly upon the number of trunk groups. It should be noted that after selection of a trunk group is made, any trunk within the group may be chosen. Therefore the output stage of the originating distribution network is a hunting stage.

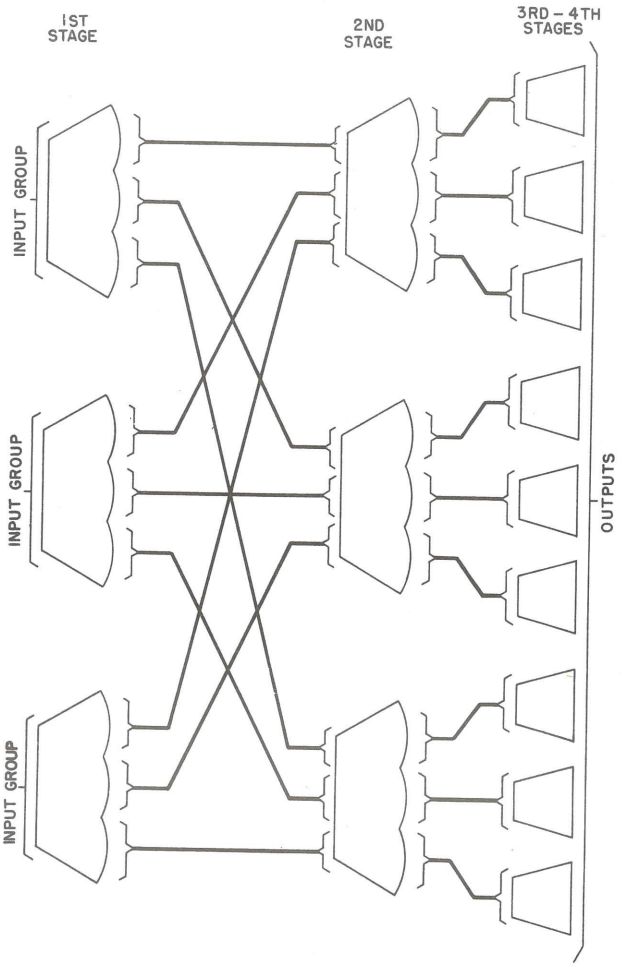


Figure 4-21 Progressive Network With 2nd Stage Inputs Combined for More Efficient Distribution

There are several significant points about the distributing stages of the progressive type of network just described which should be noted. First, the network is best adapted to a type of control which advances stage-by-stage with successive selections keyed to the digits of a numerical code. The outputs of each selection stage consist of groups of links or trunks. When the group has been selected, a particular output is chosen by a hunting process. Inputs to a stage always exceed in number the quantity of any particular output group. Since within a given period of time there is no assurance as to how many inputs will seek a particular output group, there is a possibility of blocking at each stage. With progressive control, there is no foreknowledge of busy conditions in selectable groups ahead so that progress is blind as far as choice of the link with best chances ahead is concerned. This results in some inefficiency within the network.

The network examples discussed in the last two sections have been confined to the use of ten-point switch units. These are suitable for use with a base-ten code notation and require a switching stage per code digit. More efficient use of the switching devices is possible if higher access switches are used. If the selecting access rather than the hunting access is increased, it requires a change in the number base of the code. An example of a higher access switch is the panel selector which can select one out of either twenty or fifty groups or one out of 500 individual terminals.

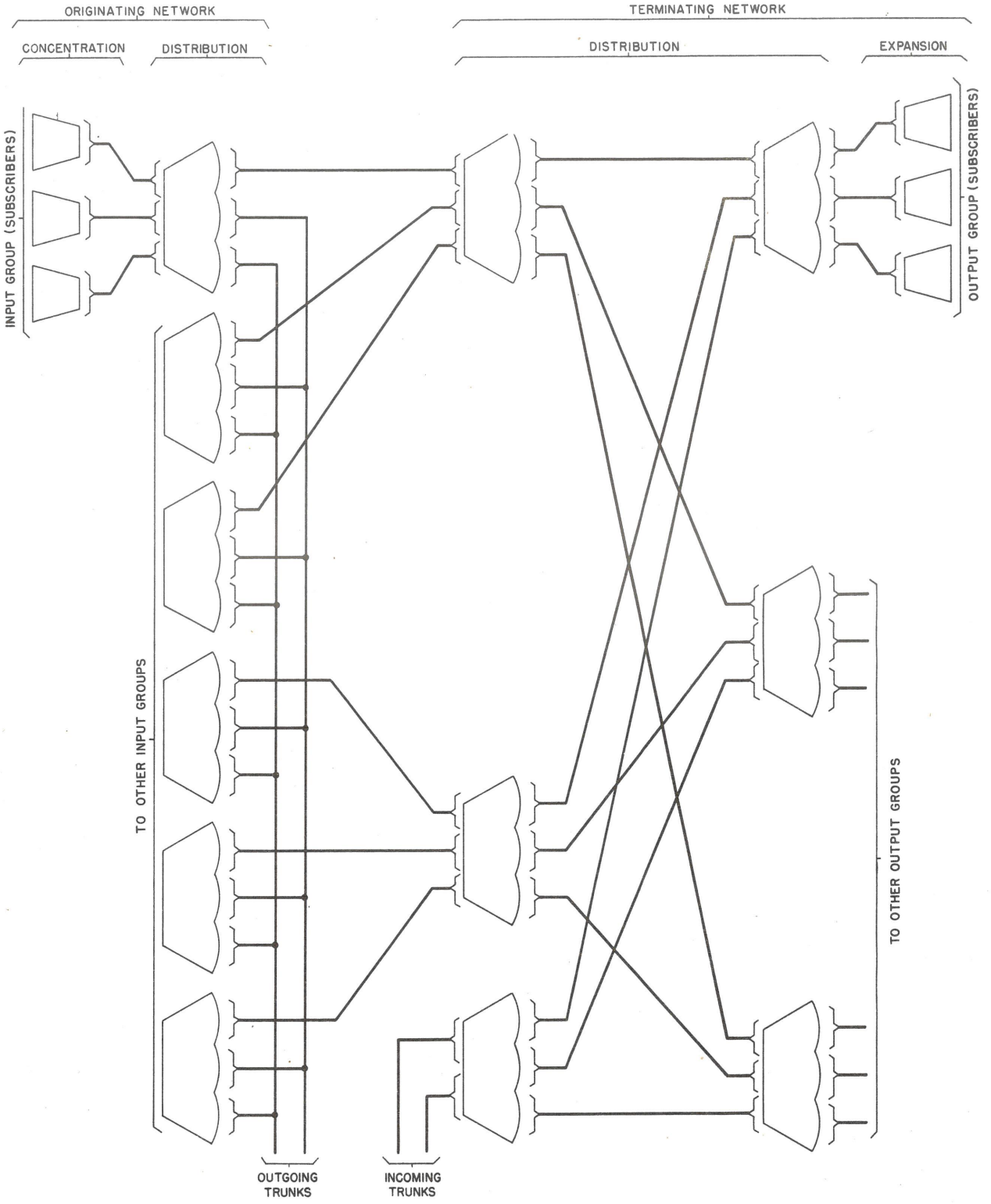


Figure 4-22 Example of Over-all Central Office Switching Network

4.6 OVER-ALL CENTRAL OFFICE PROGRESSIVE TYPE NETWORK

An example of an over-all central office switching network of the progressive type is shown on Figure 4-22. An actual central office network would be considerably more complex with more trunk groups and different multipling arrangements, but this serves to illustrate the principles outlined in the previous sections. In this example, the originating network consists of a concentration stage and a single select-and-hunt distributing stage. The terminating network consists of two distributing select-and-hunt stages and a double selection expansion stage. In controlling the establishment of a call through this complete network, an initial selection of one-out-of-ten picks a trunk group to the terminating office, a particular trunk being chosen by hunting, and four successive one-out-of-ten selections with intermediate hunting pick one particular line out of 10,000.

4.7 METHODS OF MULTIPLING SWITCHES

The most efficient use of a link or trunk hunting switch group is when all inputs have full access to all the links or trunks in the output group. However, if switch access is relatively small, the size of a trunk or link group is frequently too great to wire the group as a whole to each switch requiring access to that group. There are various ways of resolving this difficulty, including primary-secondary switch arrangements and special methods of multipling the groups to the switches. Of these only one, the so-called graded multiple, will be discussed. The graded multiple is the most generally used technique of improving the efficiency of partial access groups.

An example of a full access multiple is shown on Figure 4-23A. Every output appears on every switch and outputs can be provided up to the output access of the switch unit. With ten-point switches, this limit is ten. When the number of inputs is increased to the point where, for the desired grade of service, it overloads the output group, the multiple may be split as a tentative step in relieving the overload. This is shown in Figure 4-23B. It has been pointed out in Chapter 2 that group efficiency decreases as group size goes down. Therefore, splitting a large group results in less efficient use of the half-size groups and requires provision of more total links or trunks. This can be seen by considering a situation where sixteen outputs are adequate to handle the traffic of all the input links when wired per Figure 4-23A (assuming an appropriate switch). If the outputs are split into two subgroups of eight and wired as shown in Figure 4-23B, each half of the input links has access to eight outputs. However, momentary traffic may not divide evenly between the input groups, so that at a given moment one input group may offer ten calls while the other group offers five. The first group thereby suffers two lost calls at a time when outputs are available in the other group.

An improvement in this situation is offered by the graded multiple of Figure 4-23C. This involves wiring some fraction of the total outputs on a partial access basis and the remainder as a full access multiple across all the switches. The sixteen trunks of the example quoted above may be divided into two partial access groups of six each and one full access group of four. This offers to each group of input links a total of ten outputs, four of which are common to both groups. This is adequate to handle the presented traffic of ten and five calls without loss. However, if any of the set of five calls had been placed in the common output group, some of the set of ten calls would inevitably have been lost. For this reason it is essential that the partial access groups be placed on the switches first in the order of hunting and that the switches always start hunting at the beginning of the group. Otherwise the advantages of the graded multiple are lost. Even with this precaution, previous traffic history will leave calls from an input group connected to the common output group after connections to the partial output group have become idle, so that the graded multiple can never be as efficient as the full access multiple.

A method of showing graded multiples that is quite useful for practical purposes appears on Figure 4-24. The multiple is drawn horizontally and individual switch inputs are represented by the short vertical arrows. Intermediate inputs are not shown. Figure 4-24 illustrates sixteen outputs disposed over ten-point

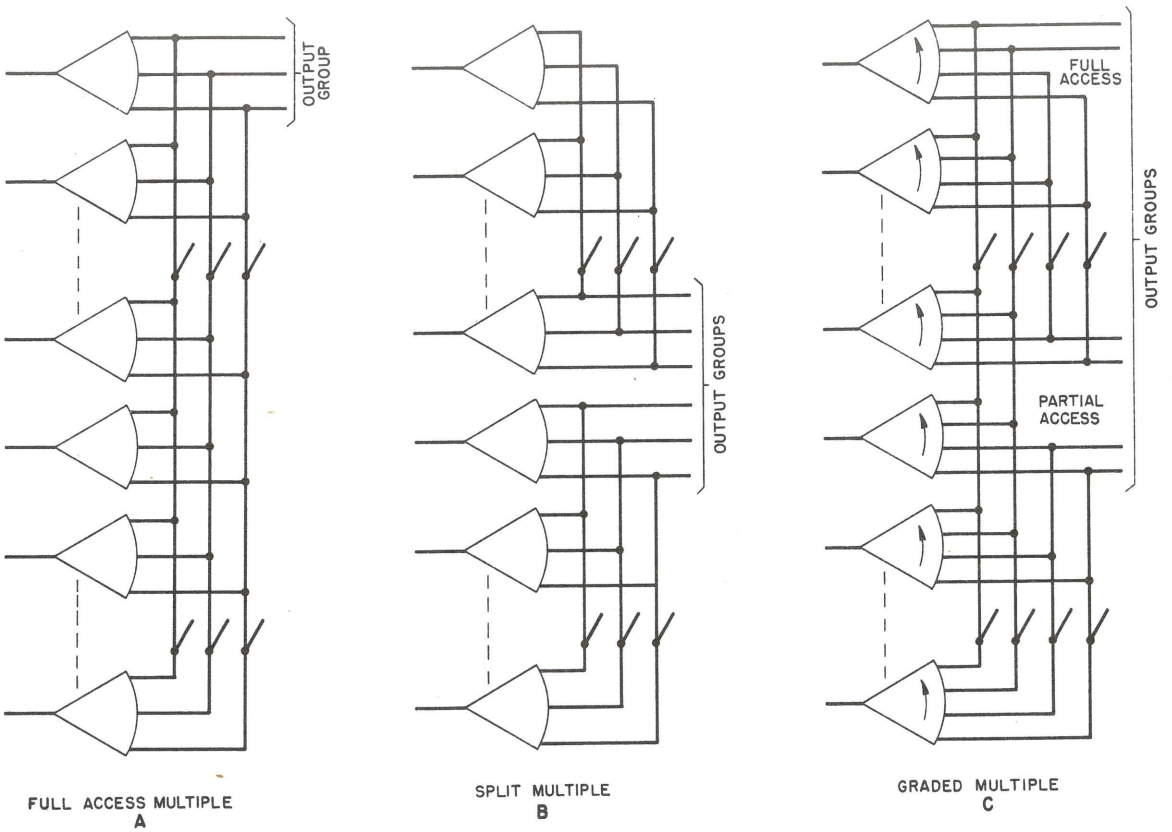


Figure 4-23 Multipling Arrangements for Hunting Groups

switches. There are usually several ways of designing graded multiples for particular values of output group size and switch capacity. Figure 4-25 shows several of these for a group of twenty outputs wired to ten-point switches. In general, the optimum arrangement is that in which the number of partial outputs before an input is equal to the number of common outputs. This principle is somewhat modified when partial common groups are provided as in Figure 4-25C. In certain cases where an unbalance among input groups is known to exist, an asymmetrical graded multiple as in Figure 4-25D may be desirable.

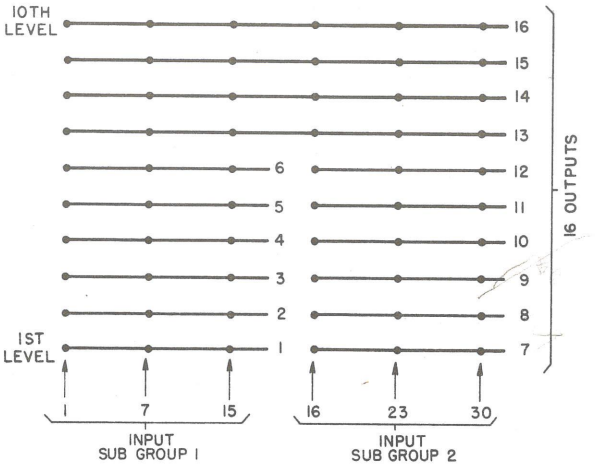


Figure 4-24 A Graded Multiple

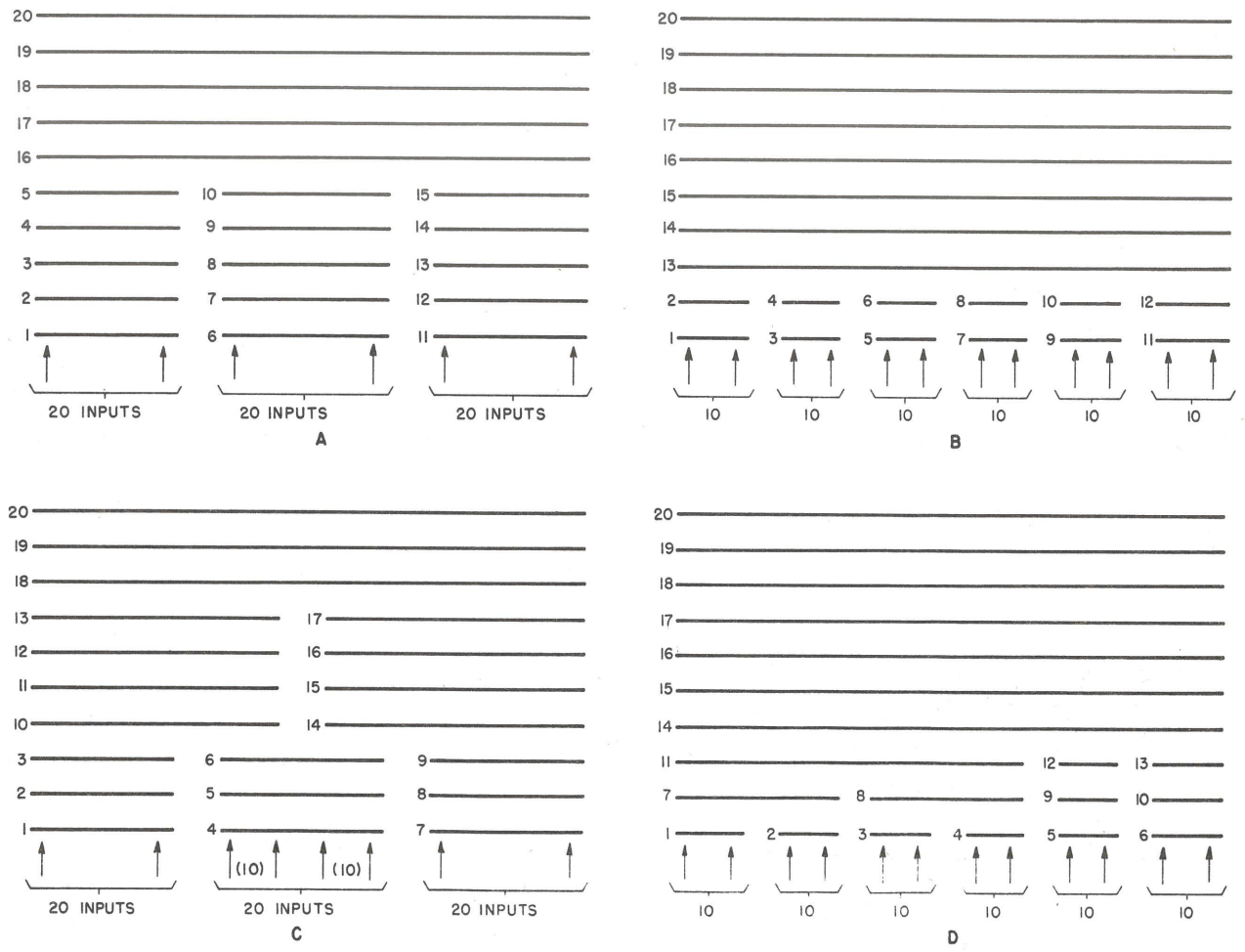


Figure 4-25 Graded Multiples With 60 Inputs—20 Outputs on 10-Point Switches

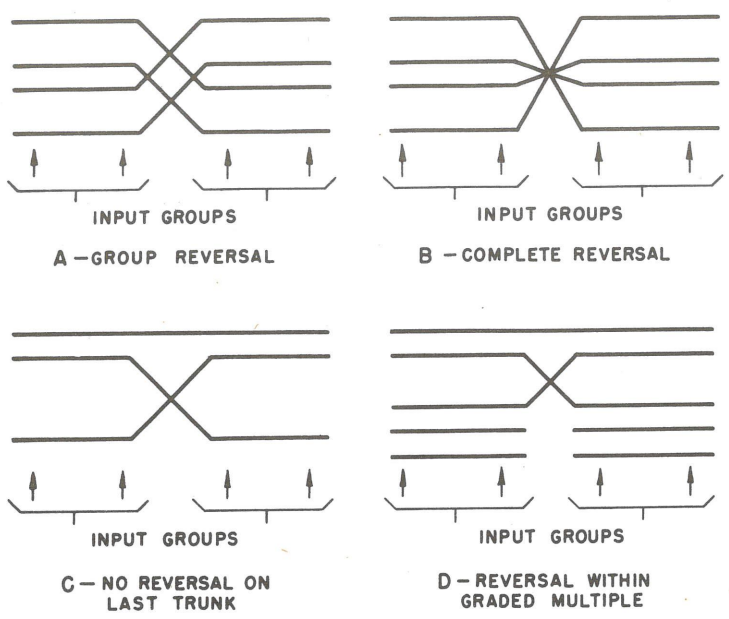


Figure 4-26 Reversed Multiples

Since the efficiency curve tends to flatten out with high numbers of outputs in a group, if the group size is large, say 100, it is often satisfactory to split the multiple into groups of 50, with grading, perhaps, within the groups, rather than attempt to grade the whole group.

In all the multiples discussed thus far, the order in which trunks or links are placed on each switch has remained the same on all switches. When all switches hunt in the same direction, which is usually the case, this is disadvantageous for two reasons. In the first place, early choice outputs receive most of the traffic and are subject to excessive wear. Secondly, and this is true only of mechanically moving switches, when traffic is heavy, half the switches on the average must travel into the upper half of the terminal group to find an idle output. This increases hunting time which should be kept as low as possible.

There are two methods of multipling which are of benefit in this situation. The reversed multiple, shown on Figure 4-26, is most frequently used. The outputs can be reversed in groups as in Figure 4-26A, or the entire set can be reversed as in Figure 4-26B. The result is that different switches see different outputs as first choice. In using the reversed multiple, the reversal takes place only once between two switch groups equal in size. It frequently is desirable to keep one output as final choice to all inputs as in Figure 4-26C. Choice of this output then indicates a group busy condition.

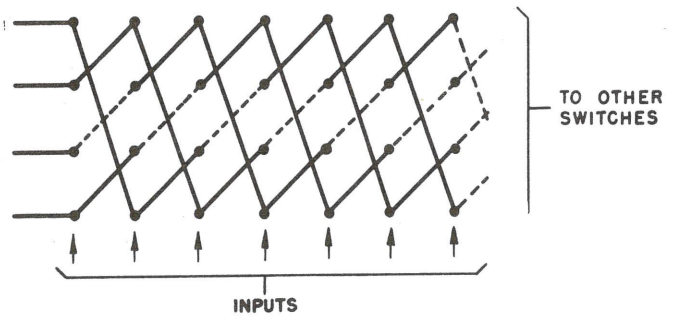


Figure 4-27 Slipped Multiple

Another multipling method, less frequently used since it increases the difficulty of wiring, is the slipped multiple of Figure 4-27. Here the outputs are slipped up one position in the hunting order in a regular progression. Either individual outputs may be slipped or small groups of outputs taken as a unit. The slipping may take place from switch to switch or from one small group of switches

to the next. This technique is sometimes used in disposing subscriber lines on line finder switches to reduce finding time. When a subscriber originates a call, control means prefer line finder switches on which the subscriber's line is most advantageously placed.

4.8 SWITCHING GRIDS

In developing the expansion and distributing stages of the progressive type of network (section 4.4 of this chapter) it was noted that the multipling arrangement of Figure 4-15 or 4-16 on the first-stage switches would be economical. However, the plan was discarded because of the high probability of blocking at the between-stage links, since only one path exists from each input group to each output group. The use of economical two-stage switches justified the addition of hunting stages in developing a workable progressive type switching network, but the number of switch units involved is too great for this plan to be feasible where the switch unit is basically a one-stage structure. Therefore, additional study of networks of the type represented by Figure 4-16 is justified to attempt to prove them in from a traffic standpoint.

The network of Figure 4-16 is reproduced in Figure 4-28 in a somewhat different symbolic form. Each input group and each output group of multipled switches is replaced by a block which may be considered to have ten inputs and ten outputs. The value of ten is this example is solely for illustrative purposes.

Within each block the switches can connect any input to any output. The switch units within the blocks may be either forward or backward-facing without affecting the validity of the network as a connecting means. The ten outputs of each input switch block fan out equally to the ten output switch blocks to give a total of 100 links spread uniformly between inputs and outputs.

The disadvantage of this network in providing only one link between a group of inputs and a particular output also obtains in the situation where the desired output is any one of a group of identical outputs if that whole output group is all placed on one output block. However, if each output group (group size assumed to be ten) is spread equally over the ten output blocks, each individual output of a group is accessible to a separate link from a particular input group. Thus, any input can reach an output group via ten links, but a particular link and a particular output must be matched for a successful connection. This type of network, then, provides adequate access into an output group

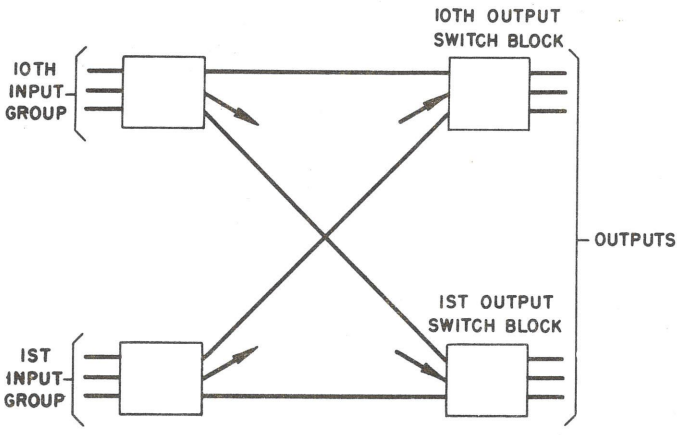


Figure 4-28 Two-Stage Grid Network

if the associated control means is capable of matching an idle output with an idle link before operating the switches to close the path. This type of control is known as common control in distinction to the progressive control which involves picking an idle link before testing the output. With the latter method, there is too high a probability that the particular required output corresponding to a chosen link would be busy while usable outputs on other switches are idle. In the further development of this grid type of network, it will be assumed that common control is utilized in setting up connections.

Although the possibilities of the grid type of network will not, at this point, be fully explored, it is worthwhile to present in somewhat more detail the physical structure of a two-stage grid. As will be seen later, this is a basic form which is frequently used as a unit in large-scale switching networks. The individual switch blocks of which the grid is composed are usually all identical in nature. Although they may be formed from groups of any type of switch unit, they are generally built up of units specifically designed for this type of usage. The best current example is the crossbar switch, shown on Figure 4-6B. The crossbar switch consists of either ten or twenty vertical units mounted together on a common frame. Each vertical unit in effect is a ten-point switch in which connection from a common terminal to one of ten individual terminals is performed by electromagnetic closure of relay-type contacts. The corresponding individual terminals of all vertical units can be multipled horizontally so that each input

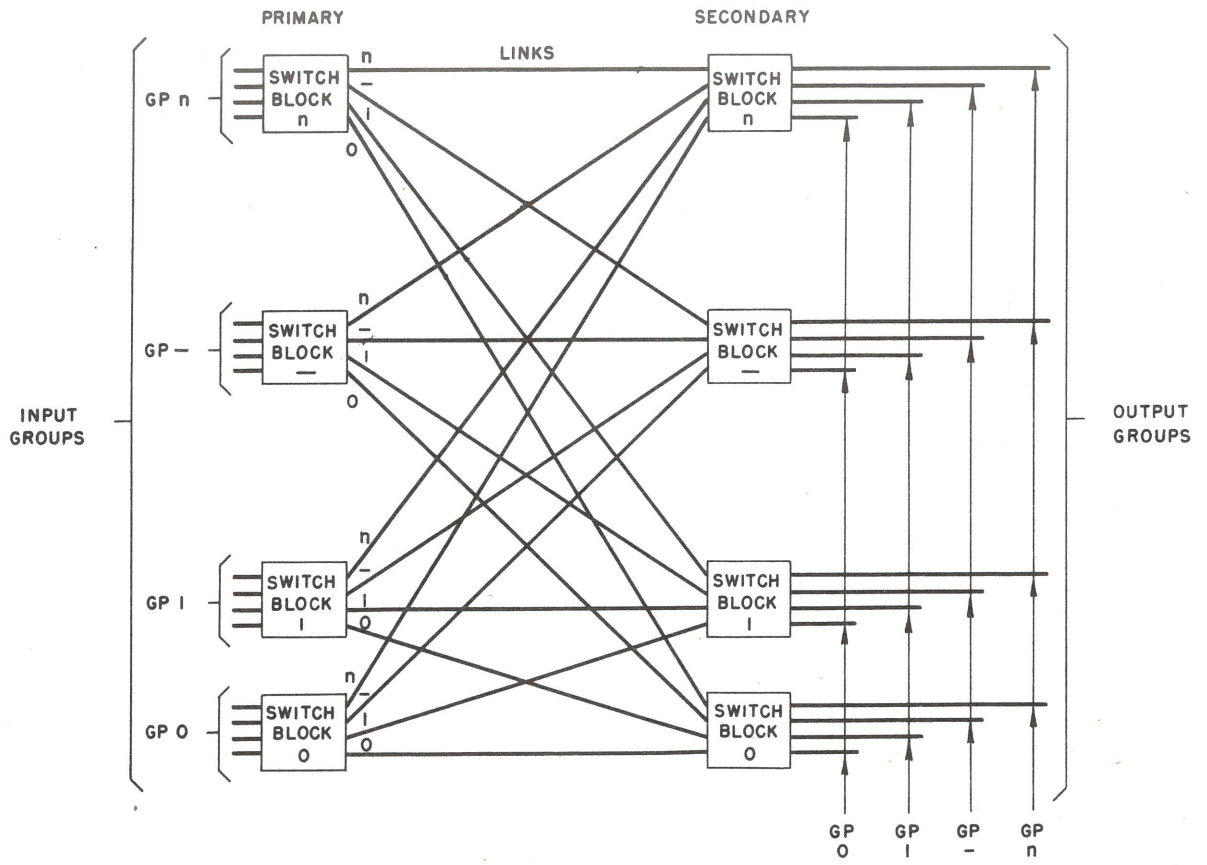


Figure 4-29 Basic Primary-Secondary Grid

on the vertical side can connect to any one of the ten outputs on the horizontal side. As a matter of fact, since the whole switch structure represents a coordinate grid with each cross-over of horizontal and vertical forming a connectable crosspoint with no directional motion, either side can be considered as input. In practice, the horizontal multiple is wired as desired to obtain flexibility in possible groupings of switches.

The general two-stage grid using switch aggregates of the crossbar type is shown on Figure 4-29. The input switches of the grid are usually designated primary, and the output switches secondary. The basic interconnection requirement is that each primary switch group have access via at least one link to each secondary switch group. The link spread between switch groups is almost invariably laid out in an orderly fashion for ease of control. For example, in Figure 4-29, note how the 0 outputs* of all primary switch groups connect to the 0 secondary switch group, the 1 outputs connect to the 1 secondary switch group, and so forth. Thus, in allocating secondary terminations of links, the output terminal number on the primary switch designates the secondary switch number, and the primary switch number designates the secondary switch terminal. This is characteristic of primary-secondary grids.

With crossbar switches, a convenient size for the grid is ten switches high, both primary and secondary. The link groups per switch may be either ten or twenty** although in the latter case the links are usually considered as two groups of ten per switch. If greater input or output access is required, as when concentration or expansion is desired, this can be obtained by multipling additional switches to each primary or secondary switch. For example, if the links are connected to the horizontal multiple on the primary switches, by extending the multiple through other switches as many additional inputs as required can be added per input group. This process is known as "building out." An example of buildout is shown on the final stage of the network of Figure 4-31.

When it is recognized that a two-stage grid wired as in Figure 4-29 is satisfactory for connecting from any input to one of a group of outputs, it is not difficult to extend the grid to provide for connection to a particular output. It is only necessary to add a third stage, the links to which will duplicate the link spread between the first two stages. This is shown symbolically in Figure 4-30 where each stage is assumed to be ten switch blocks high

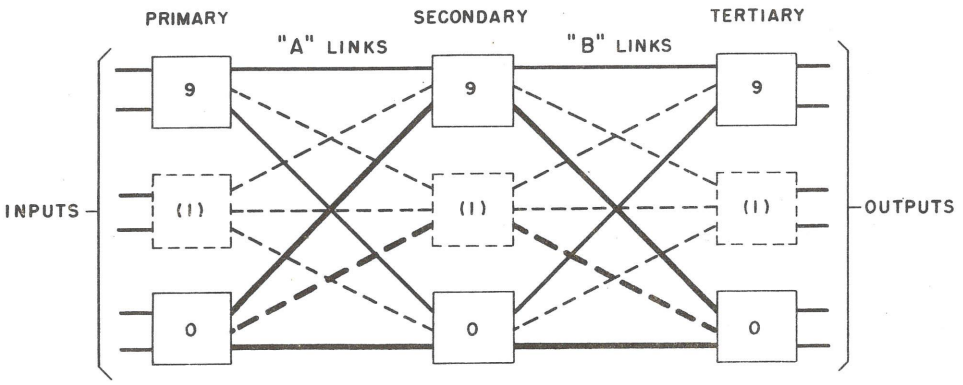


Figure 4-30 Three-Stage Grid

*In grid-type networks it is customary to start numerical designations with 0 instead of 1.

**There are sometimes situations in which the link spread is different from that described, but these are special cases.

(N=9). Examination of this network will show that any single network input can be connected to any single network output over ten matching pairs of paths, generally called channels. To determine the set of ten paths that can be used, it is only necessary to know the input and output switch blocks involved. The identifying numbers of both links in a matching pair are the same when the numbers are assigned according to the position of the link on the switch blocks of the primary and tertiary stages.

For a call between an input on primary switch block 0 and an output on tertiary switch block 0, the links that can form permissible channels are shown in heavy lines on Figure 4-30. If the input were on primary switch block 1 while the output remained unchanged, a new set of "A" links are required to match with the original set of "B" links. Since the links that make up the matching channels are available to more inputs and outputs than there are links, blocking on a particular call can occur. Since a channel can be made busy by either link in a matching pair, idle "A" and "B" links may, and frequently will, exist in the busy channel group. The hazard of blocking is reduced if the control means always assigns channels in a definite order instead of at random. This process is called "packing."

In section 4.4 of this chapter a network of the progressive type was developed to connect from 100 input links to 1000 outputs with an expected maximum of ten calls into each output group of 100. The total number of ten-point switches required was 2200. The three-stage grid network of Figure 4-30 can be modified to provide the same connections by building out the tertiary stage so that each tertiary output group is 100. This is indicated on Figure 4-31 in which the block symbols of Figure 4-30 are replaced by the crossbar switch convention. If each crossbar switch is assumed to be the equivalent of ten ten-point switches, it can be seen that the total number of switch units required by the network is 1200. This indicates a considerably increased efficiency of switch usage over the progressive type of network. This statement is made in a qualitative sense since, although comparable in traffic handling ability, the two networks are not exactly equivalent. It is important to note the fundamental difference between the two types of network. In the select and hunt network of Figure 4-20, a path is built up stage by stage, always with a choice of ten paths ahead of each link until the final output is reached. In the grid network of Figure 4-31, it is only when the network as a whole is examined that a choice of ten paths between input and output is found. Working from within the network, only one path ahead toward a predetermined output can be found at the intermediate stage.

The three-stage grid is not generally suitable as an overall network because of the relatively limited number of paths it provides. However, it is useful for certain PBX and CDO applications. In central office systems, the interconnecting paths are most frequently made up of a network of two stages of primary-secondary

grids, which network is, in effect, a four-stage grid. A typical arrangement of these grids is shown on Figure 4-32. The fourth stage, which actually is the primary stage of the output grids, results from the splitting of the secondary switches of Figure 4-31 in order to give an increased linkage spread within the network. For this reason it is not necessary to distribute the interconnections between grids (called junctors) in the same manner that links are fanned out within a grid. It is merely required that at least one junctor per secondary switch of each input grid connect to one primary switch of each output grid. The junctors are wired between switches of corresponding number on the opposing grids. This provides as a minimum one junctor to match with any pair of originating and terminating links. If the junctors are numbered in accordance with the number of the switch on which they originate or terminate, a simple system of coordinating links and junctors in channels results. For example, if on Figure 4-32 an input on input grid 0, primary switch 0 requires connection to an output on output grid 1, secondary switch 1, ten channels are available utilizing a particular "A" link group, a particular "B" link or junctor group, and a particular "C" link group. Within the link groups, "A" link 0, "B" link (junctor) 0, and "C" link 0 are capable of matching, "A", "B", "C" links 1 are capable of matching, and so forth. With this wiring scheme, previous calls equal in number to the size of the link or junctor group can block a call to an idle output, since any single element in a channel makes the whole channel busy.

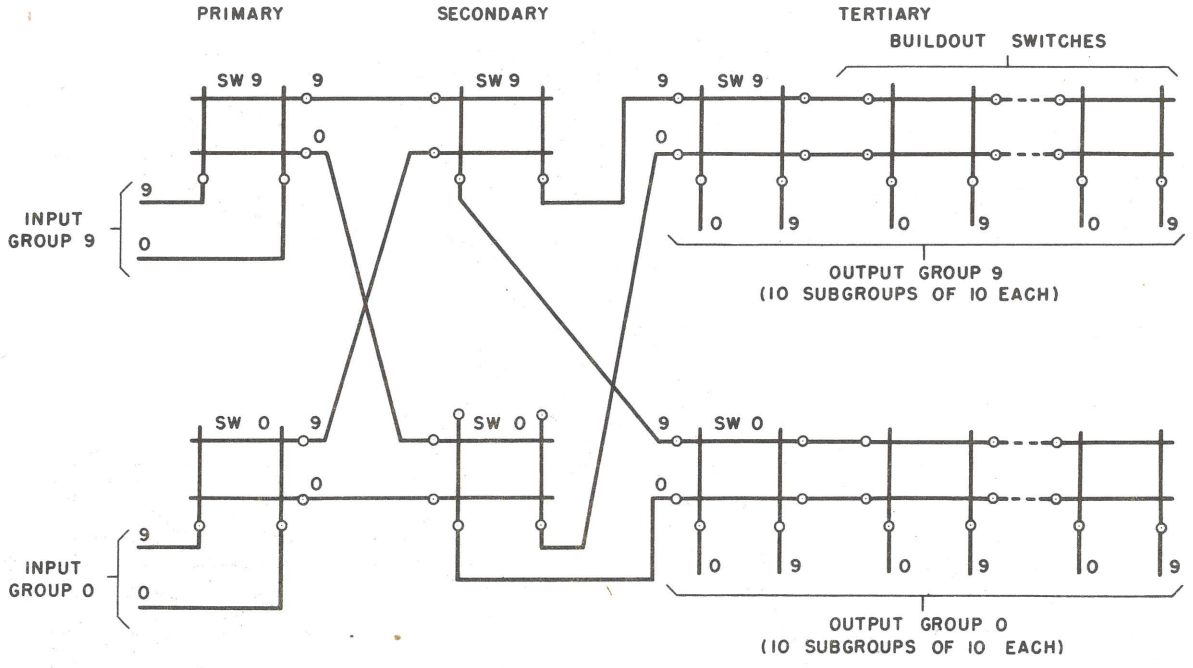


Figure 4-31 Three-Stage Grid With Tertiary Buildout (Using Crossbar Switch Convention)

The basic network of Figure 4-32 can be modified in various ways. Buildout switches can be added to provide greater input or output access or increased junctor capacity. Building out simplifies the design of the concentration and expansion network stages and permits them to become an integral part of the distributing grids. If the number of grids is such that a single group of junctors between grids does not utilize to the full the access of switches on which the junctors terminate, additional junctor groups can be provided. This provides an alternate choice of junctors in channel matching. Multipling of junctor groups is desirable in some cases where the number of input grids is not equal to the number of output grids.

Since the junctors from each input grid are divided equally among all output grids, it is necessary that traffic balance be carefully maintained on the grid inputs and outputs. In the case of Figure 4-32, the 100 junctors from a particular input grid divide into groups of ten to each output grid on the assumption that

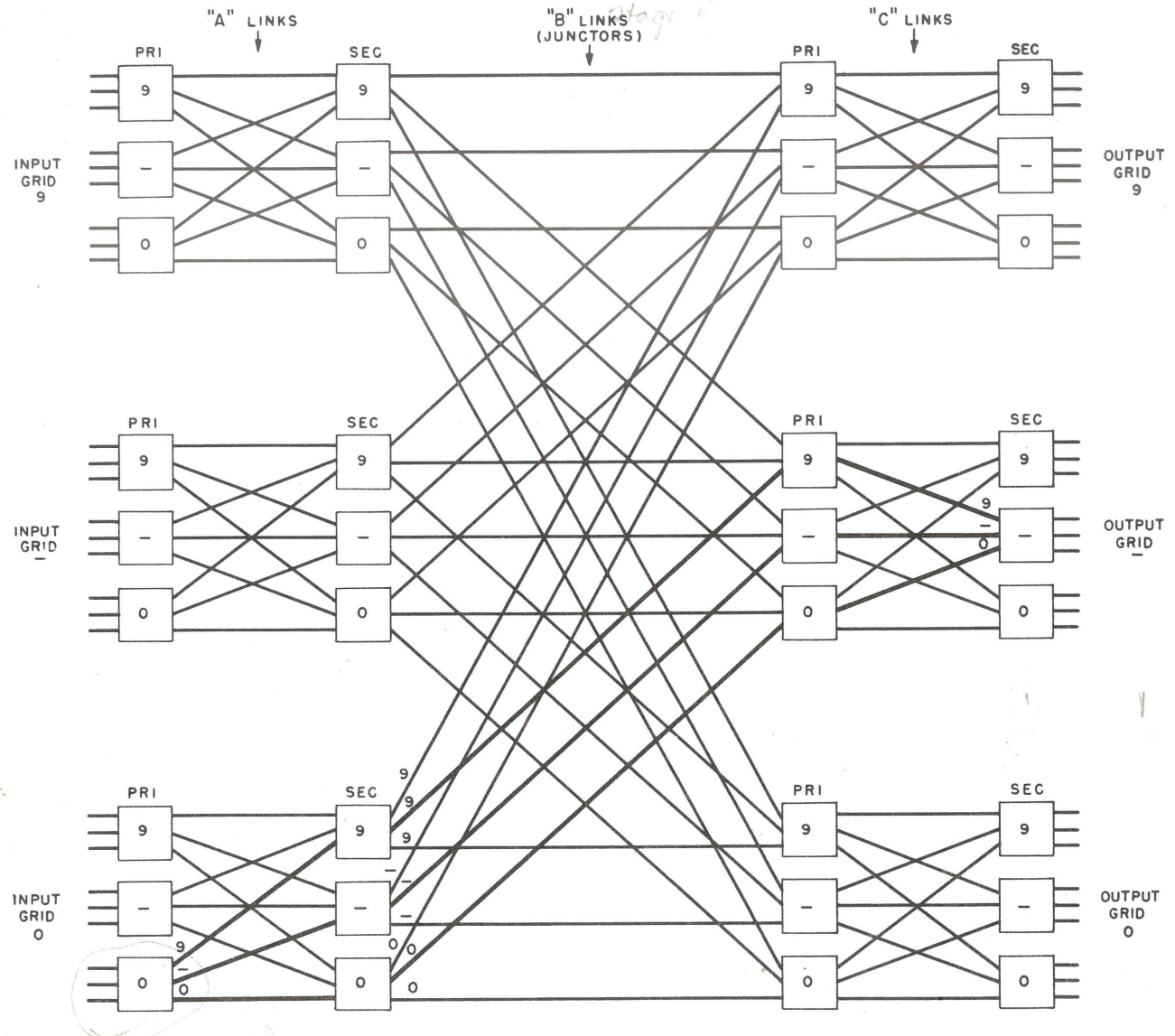


Figure 4-32 A Network of Grids

traffic is equal to each of these output grids. If excessive traffic developed to a particular output grid, the probability of failure to match due to busy junctors would increase unduly.

If the outputs of the grids consist of trunk groups where any one of the group is satisfactory on a particular call, the groups can be spread in any convenient manner over the secondary switches of the output grids. The attempt is generally made to obtain as wide a distribution as possible over both switches and grids for traffic reasons and to minimize loss because of switch or circuit troubles. This spread is possible because the busy-test and trunk hunting functions can be removed from the network and concentrated in the common control circuits.

4.9 CENTRAL OFFICE GRID NETWORKS

The progressive type of switching network is inherently unidirectional insofar as path establishment is concerned and hence the switching system interconnection function usually takes the form of Figure 4-1. However, the grid type of network is bidirectional in that path establishment is between two terminal points and it does not make much difference which end is considered input. Advantage may be taken of this by using parts of the network for both originating and terminating purposes. This results in more efficient use of the switches and the interconnecting links and junctors. Another big advantage when the concentration and expansion stages are combined is that each subscriber's line has only one appearance on the network. This reduces the installation wiring and maintenance problems considerably.

One form of the combined network in current use is that shown on Figure 4-33A. The originating and terminating distributing stages are for the most part separate, but the concentration and expansion stages are a common network. This over-all network is similar to that used in the No. 1 Crossbar System.

In No. 5 Crossbar, the combining is carried further to give the over-all network shown in Figure 4-33B. Here all stages are bidirectional in use and inputs and outputs appear at both ends of the network.

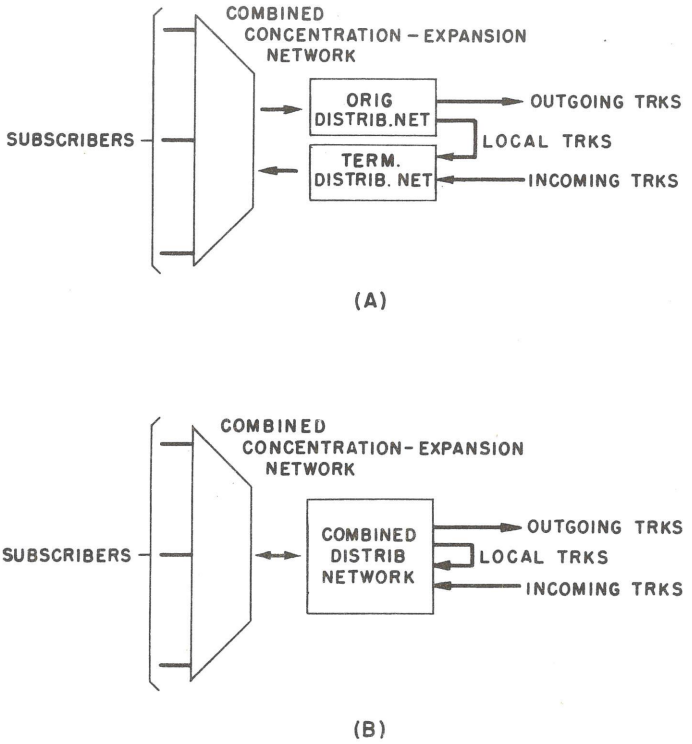


Figure 4-33 Combined Forms of Central Office Network

CHAPTER 5

SWITCHING SYSTEM PRINCIPLES, PART III—PROGRESSIVE CONTROL

5.1 INTRODUCTION

In Chapter 4 the general principles involved in laying out the interconnecting networks for automatic switching systems were discussed. In this and the next chapter, the fundamental principles of the control means necessary for setting up connections through such switching networks will be taken up.

It will be recalled that the distribution and expansion stages of the network developed along two main lines which were designated progressive type and grid type. Each of these networks is fundamentally suited to a distinct type of control means. The two types of control means, basically different in principle and nature may be called progressive control, applicable to the progressive network, and common control, applicable to the grid network. These broad classifications of course do not specify in any way the circuit, apparatus, or techniques employed to product the control actions.

The progressive type of control requires that the path-selecting action advance stage by stage through a tree-type switching network under the influence of successive control signals which originate at a point ahead of the selecting stages. The selecting action at each stage chooses a group of identical paths which lead toward the ultimate destination, and one of the group is picked in competition with other circuits by a hunting action. In general, the progress is blind, in that there is no foreknowledge of conditions beyond the immediately chosen path until a final selection results in connection to the called line. The basic principles of progressive control will be covered in this chapter.

Common control is a term with many implications which can be defined in a broad as well as a specific sense. From the broad point of view, which is of relatively minor importance in these chapters, common control implies any control means which is employed in common by more than one switching device. This, as a principle, not only may have certain obvious economic advantages, but its use is sometimes imposed by circuit considerations. For example, if an input is multiplied to more than one switching device (perhaps backward-facing switches), a common circuit is necessary for control purposes. On this basis common control circuits may appear in systems which are fundamentally progressive in nature.

When discussing common control as a basic principle applicable to over-all switching systems, however, a somewhat more rigorous and specific definition is

required. Under these circumstances common control shall be specifically understood to denote a control means which, on the basis of integrated information, first determines the output and input terminals which must be connected through the network and then tests and establishes a path between them. Usually all permissible paths through all switching stages are examined simultaneously by the control means insofar as circuit techniques permit. In systems where the central office network is divided into originating and terminating halves, independent common control means may be utilized by each half. The principles of common control are taken up in the next chapter.

Progressive control can be broken down into two subclasses which are of primary importance and produce in effect two major categories of switching system control means. These divisions of progressive control are rather distinctly different and will be treated as separate entities. If the switching network is under the immediate and direct control of the subscriber's calling device, the system is designated direct progressive control. If control of the network is by means of an interposed circuit known as a register which accepts and interprets directions from the subscriber, subsequently operating the switches, the system is designated register progressive control.

Common control systems, in which, incidentally, the register in some form is always used, may take a variety of configurations which differ primarily in type of apparatus and circuit-network relationship. The usual form might be called concentrated common control in which all control functions are performed by coordinated circuits grouped together in definite equipment units. Each major control unit, frequently known as a marker, has its own access to the switching network. Another form might be called distributed common control in which there is no master control unit, but rather an aggregation of functional circuits distributed over the switching network stages. This form is still in the experimental stage and is not so well defined as the concentrated common control. For this reason common control will be discussed as a single category of systems with major emphasis on the concentrated type, but some of the implications of the distributed type will also be discussed.

Within each type of control category there are wide differences from system to system which may generate additional classifications of switching control means. Discussion of these variations will not be included in this chapter. However, generalized examination of direct and register progressive control systems and common control systems will indicate certain logical potentialities, arrangements, and principles inherent in each type of system. These should be applicable respectively to any particular system falling within the appropriate category. These broad principles are developed in this chapter.

5.2 CONTROL OF CONCENTRATION STAGE OF NETWORK

Before entering into the detailed discussion of control means, it would be well to dispose of the control methods applicable to the concentration stage of the switching network. The concentration stage often is essentially independent

of the selection stages and need not comply with the basic control methods applicable to the latter. In this respect the control of the concentration stage frequently offers an apparent anomaly when judged against the control employed with the other stages of a particular system. For example, progressive type systems usually employ in the concentration stage control means common to the switching devices. This should not affect the viewpoint that the system as a whole belongs in the progressive control category.

Two varieties of concentration were discussed in Chapter 4, one employing the line switch principle and the other the line finder principle. A third variety in which a grid network is employed will be taken up in the next chapter under common control. The applicable control means for line switch concentration is shown on Figure 5-1A. The circuits of the attending function react to the origination of a call by a subscriber and notify an individual control means associated with the line switch. The control means drives the switch to the first idle link and then usually causes the removal of the attention signal. This control method can be considered as an oversimplified form of direct progressive control.

When the line finder network is used, as in Figure 5-1B, there is no specific switch which a particular line can direct, and common control means are necessary. The attending functions of all lines associated with the same group of line finder switches are tied together and any one can actuate a common control circuit. In addition, the attending function of each line will mark its associated switch terminals when service is required. The common control will allot an available switch and either directly or via an individual switch control will cause the switch to find the marked calling line. With this type of control, the circuits must definitely cause removal of the attention signals as soon as the line is found. It is inherent in this type of arrangement that if two or more calls originate within a short time interval, the first to originate is not necessarily the first served. Within a group, in general, only one line finder can act at a time since lines request service over a common lead. The common circuits and the switches must be fast-acting to reduce delays to other lines that may be waiting.

With control means of this type, it is clear that a trouble condition in the common control circuit may put an entire group of lines out of service. This is a condition that usually is not tolerated in telephone switching. One recourse often used is to provide a duplicate or emergency common control circuit which can be switched in if trouble is encountered.

Another method, particularly applicable to line finder control, is to divide the line group into two subgroups with an individual common control circuit per subgroup. Under normal conditions each subgroup utilizes its own control circuit; in an emergency, one control circuit can handle the whole group. This arrangement is shown on Figure 5-1C. Each line subgroup appears on all line finder switches. However, between the switch subgroups the line multiple is reversed so that the lines appear in the most advantageous position for rapid finding on the normally used switches. In normal operation, the control circuits function independently, but if one cuts out because of trouble, the other can assume the whole load to

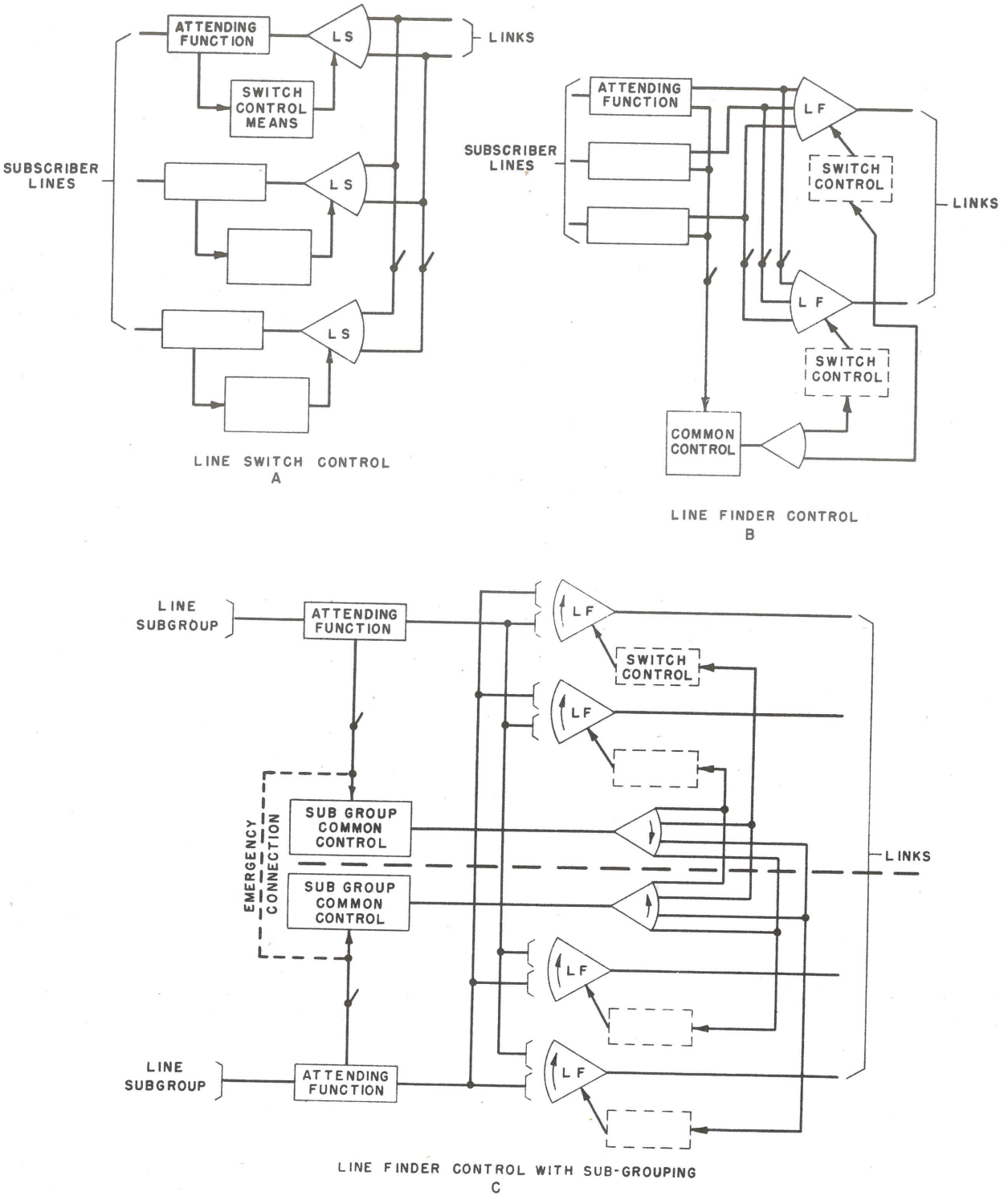


Figure 5-1 Control of Concentration Stage

give adequate, although less rapid, service. Note also on the arrangement of Figure 5-1C that if all line finders in one subgroup become busy, a control circuit can allot finders in the other subgroup. Under some circumstances it is not feasible to multiple the line subgroups to both line finder subgroups so that this type of overflow operation is not possible.

Since common control line finder concentration is generally more economical than line switch concentration, the former method is usually employed, even in progressive type systems. As mentioned previously, this does not modify the essential characteristics of the progressive system. With either method of concentration, the assignment of lines to line finder or line switch groups is independent of directory number. Insofar as possible, the assignment is such that average originating traffic density is the same among all groups.

5.3 DIRECT PROGRESSIVE CONTROL

By definition, in a direct progressive control system, the selecting switches of the interconnecting network are under the direct control of the calling device of the subscriber's telephone instrument. The information transmitting function performed by the subscriber merges into the control function whereby control circuits in the central office operate in response to control signals from the subscriber. The registration of the information transmitted by the subscriber is performed by the interconnecting switches themselves rather than by separate circuit units. This implies a fixed coordination, a "gearing" of the calling device to the switching device, with each one imposing restrictions on the other. Thus the signals constituting the called line code which are generated by the calling device must be of the type capable of driving the chosen switch mechanism. Furthermore, the calling device must be maintained to the tolerance limits required by the central office equipment. Once the signaling technique has been established, improvements in switching mechanisms* must not extend to major changes involving control signaling. As will be seen later, even interoffice control signaling within limited areas is performed by the subscribers so that radical changes in signaling technique would affect not only all the switching mechanisms of a particular central office, but all associated offices as well.

A direct consequence of the progressive type of network with direct control is that assignment of a numerical code to a subscriber specifically fixes his line location on the output switch stage. If care is not exercised in line assignment, a concentration of subscribers with heavy terminating calling rate may occur, within a particular hundreds group for example. There will then be traffic unbalance through the network. This situation is difficult to remedy one it has developed since subscribers are in general reluctant to have their numbers changed. The same thing is true of trunk groups to other offices. Once codes have been assigned, there is very little flexibility in reassigning routes to take care of changes in traffic patterns between groups of offices. Line assignments on the input or line finder switches, incidentally, are independent of code and may be shifted as desired for traffic efficiency.

This fixed relationship between line or trunk location and the assigned code imposes another restriction upon direct progressive systems. Once the subscriber

*This is true only when the system remains within the category of direct progressive control.

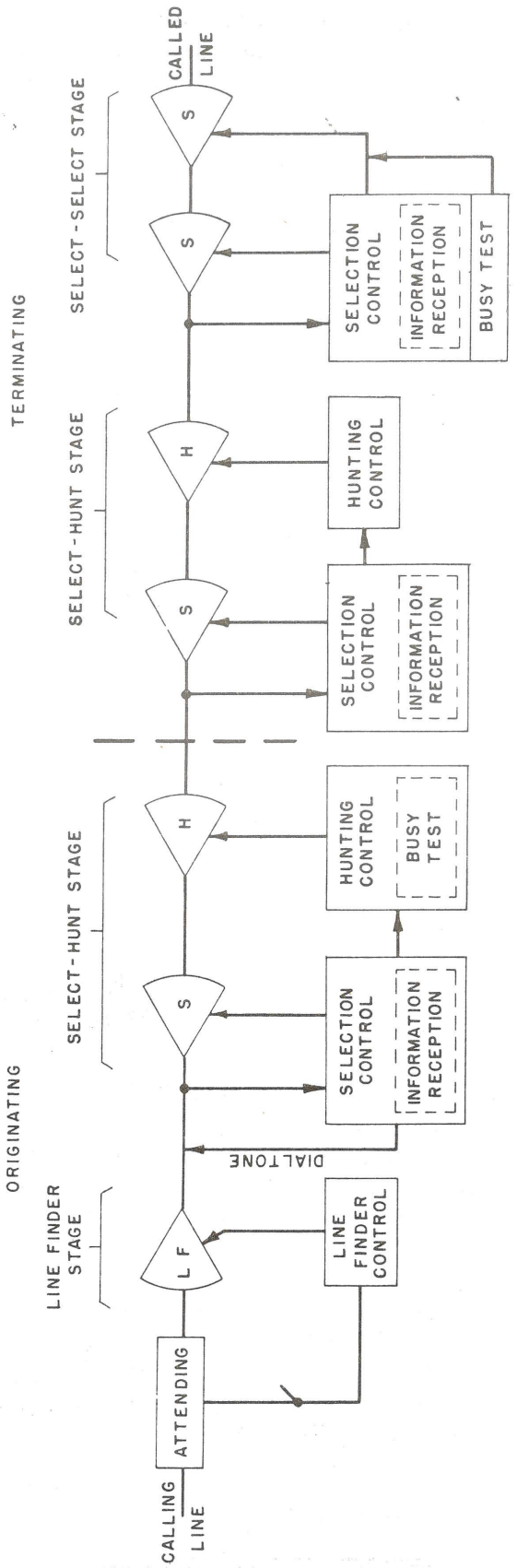


Figure 5-2 Relation of Control Circuits to Switches—Direct Control

has transmitted control signals, there is no possibility of trials of alternate sets of paths or trunks if an all-busy or a trouble condition is encountered anywhere along the path first chosen through the network. The only recourse is to inform the subscriber of trouble by tone signal and let him start again.

Control Signaling

The switching network applicable to direct progressive control builds up the connection on a stage-by-stage basis. Therefore the control signals must consist of a set of successive, discrete signals, each one, in time order, to be associated with the control of a particular stage of the switching network. Since most telephone lines are historically identified by an office name and a number consisting of four or five digits in the standard decimal numbering system, it is imperative that automatic telephone signaling conform with this practice. Although it is customary to use alphabetical letters for central office and party identification, in telephone signaling each letter is represented by a numerical digit. Therefore the successive control signals generated by the subscriber with his calling device correspond to individual digits ranging from 1 to 10 (or 0).

Since the numbering plan is confined to a base-10 system, each switch stage is limited to an output access of ten for selecting purposes. The number of digits required for signaling is a direct function of the number of stages necessary to reach all central offices (and special service outlets such as operator, information, and so forth) directly accessible to the subscriber and all subscribers within a particular central office. This is sometimes modified by the desirability of having all codes within a region represented by the same number of digits. In this case, central offices which do not require all the specified digits resort to artificial absorption of one or more digits.

The character of the signals within each digit of a set offers, theoretically, some possibility of variation, and in general does not affect any principles inherent in the direct progressive control type of system. The type of signal that has proved most satisfactory for use with switches of the direct control type consists of a train of pulses, the number of pulses corresponding to the value of the digit represented. With this type of control signal, the switch mechanism advances in synchronism with each received pulse so that there is no time lag between transmission of a digit by the subscriber and selection by the appropriate switch stage.

The device most frequently, if not exclusively, used for this type of subscriber control signaling is the familiar telephone dial. With the dial, each digit is set by rotating a finger wheel through a particular angle per digit; the governor-controlled return of the wheel to normal produces the series of pulses* constituting the coded digit.

Switch Control Means and Information Reception

The relationship between the circuit means that respond to subscriber control signaling and the switch mechanisms of the network is shown on Figure 5-2. Here the complete network is represented by a single switch symbol per select or

*The pulses consist of momentary or short opens in the loop which is closed between subscriber and central office when the subscriber originates a call. Differentiation between pulses of one digit and the next is on a time basis.

hunt stage. It is clearly necessary that control means be associated with each stage, and in general this implies with each individual switch mechanism. Since the final position of each switch corresponds directly to the digital information sent by the subscriber, the control means together with the switch mechanism can be considered to incorporate the information receiving function. The control means for the selecting stages must be capable of responding to subscriber signaling, setting the switch to the desired output, recognizing the end of the digit-signal (when dial pulsing is employed) and informing the next stage to proceed. When the next stage is a hunting stage, a different self-activated control means must take over. The hunting control must cause the switch to search over the group of output links or trunks, detect and reject busy outputs, pick the first idle output (or signal the subscriber that all are busy) and cut through to the next stage. At the trunk selecting stage, the hunting action merges with and is identical to the busy-test function. As discussed in Chapter 4, the switch mechanism used in direct progressive control systems is usually of the double action type that includes both a select and hunt stage or two select stages. Therefore the select and hunt control means are intimately associated and usually physically located on the switch mechanism. The same thing is true of the double selection means generally required by the last switch stage.

The function of line busy-test in direct progressive control systems clearly belongs to the final switching stage. Busy-test, which involves detecting a specific electrical condition on the output terminals, can conveniently be integrated with switch control at the last stage. Means must be provided for by-passing the line terminals and returning a distinctive tone to the calling subscriber if the called line tests busy.

The technique of connecting an originating line to a link to the first selecting stage has been described in paragraph 5.2 of this chapter. There is no positive assurance that such connection will be made immediately or at least before the subscriber is physically capable of starting the dialing operation. Delay may occur because of competition with other lines originating at the same time or because no link is available at the instant of origination. For this reason a signal must be given to the subscriber when the equipment is ready to accept his control information. This signal, usually known as dial tone, is furnished by the first selecting stage when it is connected. Premature dialing, of course, results in a misdirected call.

The same possibilities of delay exist at all subsequent stages. Although additional dial tone signals could be transmitted at each stage, it has generally been considered preferable to require that the equipment, within certain probability limits, be ready and waiting to receive each subsequent digit as soon as the subscriber is ready. This is a rather difficult requirement to meet and, among other things, restricts the permissible number of hunting outlets per stage. This latter factor tends to reduce the efficiency of direct progressive control systems in the larger size offices.

Information Transmission to Other Offices

In direct progressive control systems the limit to the distance at which subscribers can be located with respect to the central office is largely a function of the distortion suffered by the control signals with line length. For economical reasons some subscribers are located at the limiting distances at which distortion will still permit accurate operation of the switches within the home central office. This poses a problem when control signaling is necessary between offices perhaps widely separated, since the original subscriber signals must be utilized for control at the distant point. To take care of this, signal repeaters are interposed between the two offices when necessary as indicated on Figure 5-3.

The repeater may be located either at the output point of the originating office, the input of the terminating office, or both. It serves to regenerate the original weak and distorted subscriber signals by putting out new signals at full level, with pulse correction where necessary. The use of repeaters becomes rather expensive in areas with a large amount of interoffice trunking.

The Alerting Function

The alerting function which applies the ringing signal to the terminating subscriber's line most logically belongs to the final switching stage. This location eliminates the necessity of sending signals to initiate ringing back through the switching network to an earlier point in the connection. An additional advantage of placing the alerting function at the final stage is that it simplifies the application of special ringing codes to particular lines, as is necessary in

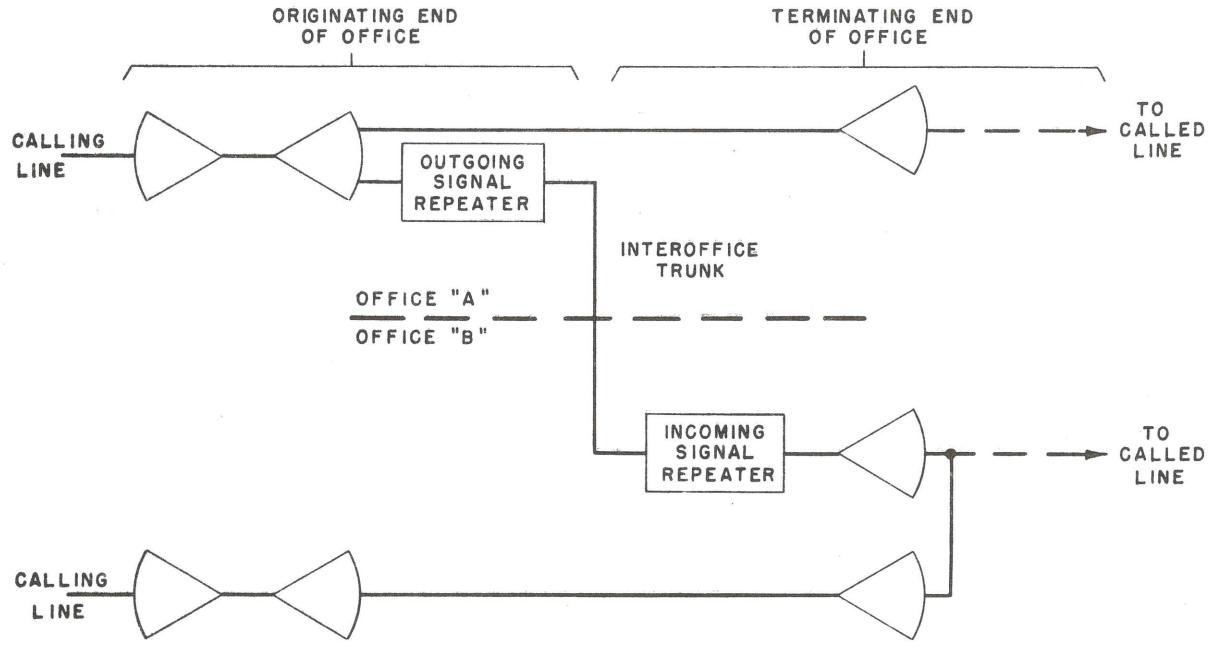


Figure 5-3 Use of Control Signal Repeaters

party-line ringing. All subscribers' lines requiring the same ringing code can be assigned numbers which group the lines on particular final connector switches wired to furnish the appropriate ringing signal. Since the supervisory means, as will be seen, is also usually placed at the final switching stage, the alerting and supervising functions can be combined to give a more efficient equipment arrangement than if the two functions were located at different switching stages.

The alerting function as applied to interoffice signaling is usually an integral part of the control signaling means and need not appear as a separate functional unit.

Supervisory Means

Some means of supervisory control is necessary both during subscriber control signaling and conversation. Supervision during control signaling is so allied circuitwise with the control signal reception means that in general the same circuits perform both functions. However, the decision must be made as to the location of the supervisory circuits during the talking period. As discussed in Chapter 3, the supervisory means should be placed in the concentrated portion of the network. One convenient location is between the line finder and first selecting stage; another is immediately preceding the final connector stage. In general, as long as the switching of the call remains within the confines of a single office, only one point of supervision is necessary.

Supervisory control at the front end of the network is shown by means of the dashed-line box on Figure 5-4. After establishment of the connection, this circuit recognizes the status of the two subscribers and serves to hold or release the switches. The supervisory control of the switches within an office is usually over a third wire through the switches, associated with but independent of the talking

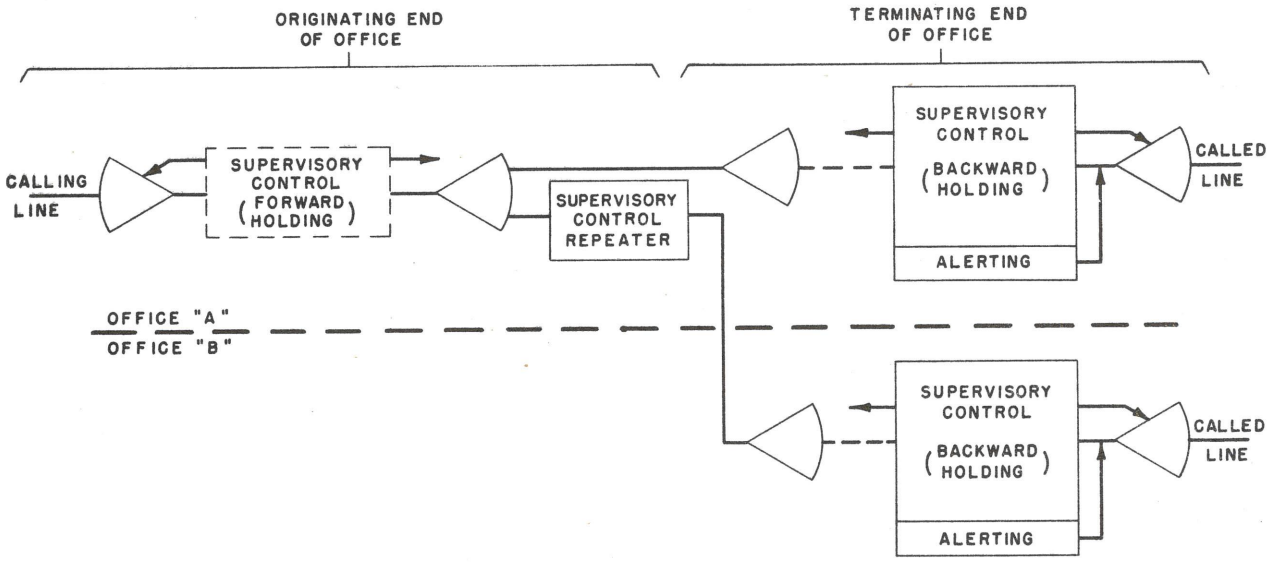


Figure 5-4 Location of Supervisory Control and Alerting

pair. The nature of the control action is normally to hold the switches locked until release time by a condition on the third wire rather than transmit a specific release signal when the connection is to be dismissed. This, incidentally, permits use of the hold condition as a busy indication during switch hunting.

Front-end supervision may be designated forward holding. Although located at an efficient stage of the network, because of the nature of direct progressive switch control, with forward holding it is difficult to design adequate supervisory circuits that do not interfere with subscriber control signaling during buildup of the connection.

Terminating end or backward holding supervision is illustrated by the solid block on Figure 5-4. With this system, as a switch circuit is added at each successive stage to the connection during subscriber control signaling, it establishes the holding condition for preceding switches. Each switch drops its own supervisory control as the next one picks up supervision. Finally, supervisory or holding control remains at the last stage during the talking period. This is the usual supervisory method in direct progressive control systems.

When a connection involves two offices, additional supervisory means must be introduced since it is uneconomical to furnish the third holding wire on interoffice trunks. A supervisory control repeater capable of functioning over the transmission conductors can be placed at the trunk output of the originating office to permit use of the regular supervisory control at the terminating office and to provide local backward holding in its own office. Since in general the same considerations affect the need for and location of the supervisory control repeater and the control signal repeater, the two are integrated into a single circuit unit placed at the originating end of the interoffice trunk.

Supervision theoretically may be under control of either or both subscribers. If both subscribers are required to hang up before the switch train can release, either one can tie up the other's line. If either subscriber alone can release the switches, there is the probability of a false call start by the subscriber who delays his hang-up because this subscriber appears to the system as if originating a new call. In practice, particularly in backward holding systems, it is necessary to give primary supervisory control to the calling subscriber. Limited control, usually over the final switching stage only, may be assigned to the called subscriber, primarily to reduce false starts after a delayed hang-up. If the supervisory scheme permits holding of the terminating line by the calling subscriber after the called subscriber has hung up, means must be provided to warn the central office personnel when such a condition persists for an unduly long time.

An inherent trouble in direct progressive control systems is the unguarded interval that exists for a short period following the release of the switches by the supervisory circuit. Since in the usual case the same electrical condition that holds the switches is used to indicate that they are busy, the busy indication is necessarily absent while the switches are in the process of restoring to normal. This introduces the possibility of premature reseizure of the switch by another

call with consequent false connections. Especial care must be taken to guard against this possibility in the outgoing supervisory or control signal repeaters. Otherwise premature reseizure of the repeater may catch the switch train in the terminating office before it has had time to release.

General Appraisal

Direct progressive control systems, while efficient and economical for smaller size installations, suffer severe limitations when applied to large offices in multi-office areas. Although the basic switch mechanisms and control means are intrinsically simple, the small access imposed on the switches by the nature of the system requires complicated and cumbersome networks when the number of subscribers is greater than a few thousand. The necessity of signal repeaters for interoffice signaling also increases relative costs in multioffice areas.

Inflexibility of line and trunk assignments and impossibility of second trial features further reduce the utility of direct progressive control in large population centers. Also, the intimate coupling of the switching devices and the subscriber's calling device prevents major changes in one without corresponding changes in the other.

An additional disadvantage, which is becoming important at present for the first time, is the difficulty of integrating direct progressive control systems with the nationwide automatic switching system.

5.4 REGISTER PROGRESSIVE CONTROL

The preceding paragraph has pointed out some of the disadvantages of direct progressive control systems, disadvantages which apply particularly to full-size offices in metropolitan multi-office areas. The chief difficulty centers on the small access switch which becomes very inefficient when incorporated in networks which must interconnect large numbers of lines and trunks. This statement of the problem intimates that at least a major part of the difficulty could be resolved by use of a large access switch. However, the large access switch introduces the additional problem of how to control it, since direct subscriber control of the switching devices was the factor that dictated use of small access switches in the first place. Behind this is the fact that it is impractical to require the subscriber to introduce control signals into a switching system on any basis but that of a decimal code.

The use of large access switches in a progressive type network, then, depends upon the provision in the central office of circuit means which can accept instructions from the subscriber in one form, translate such instructions into another suitable form, and finally reissue appropriate control signals to the switching network to guide the connection to the desired output. Provision of such circuit means not only permits the use of a more efficient interconnecting network, but immediately introduces the possibility of many other advantages which will be described in this section.

The circuit unit that receives and stores information signals from the subscriber is, in the general case, known as a register and performs the basic switching function of information reception. However, when used in conjunction with a progressive type switching network, the register also assumes the function of network control. The name which, in practice, is commonly given to the circuit unit that combines the registration and control functions is "sender." The name "sender" is also applied, by derivation, to circuits that combine the functions of information reception and information transmission, and in some common control systems, to circuits whose primary function is only information transmission. For definiteness, in this chapter, the designation "control register" will be applied to the circuit unit which receives information from the subscriber (or another central office) and utilizes the information to control a progressive switching network.

In the discussion which follows it will be assumed that the interconnecting network is of the same general nature as the progressive type network whose control was described in paragraph 5.3. Since large access switches can be utilized, the over-all number of switching stages is less than in the direct control system; otherwise the networks themselves are similar.

The Control Register

The control register must necessarily be located in the network pattern ahead of the first selecting stage. Since the line finder or concentration stage operates under common control and is independent of dialed instructions by the subscriber, a convenient position for the control register is in the link between the line finder and first selection stages. This has the additional advantage of placing the circuit in a concentrated portion of the network and is illustrated in Figure 5-5A.

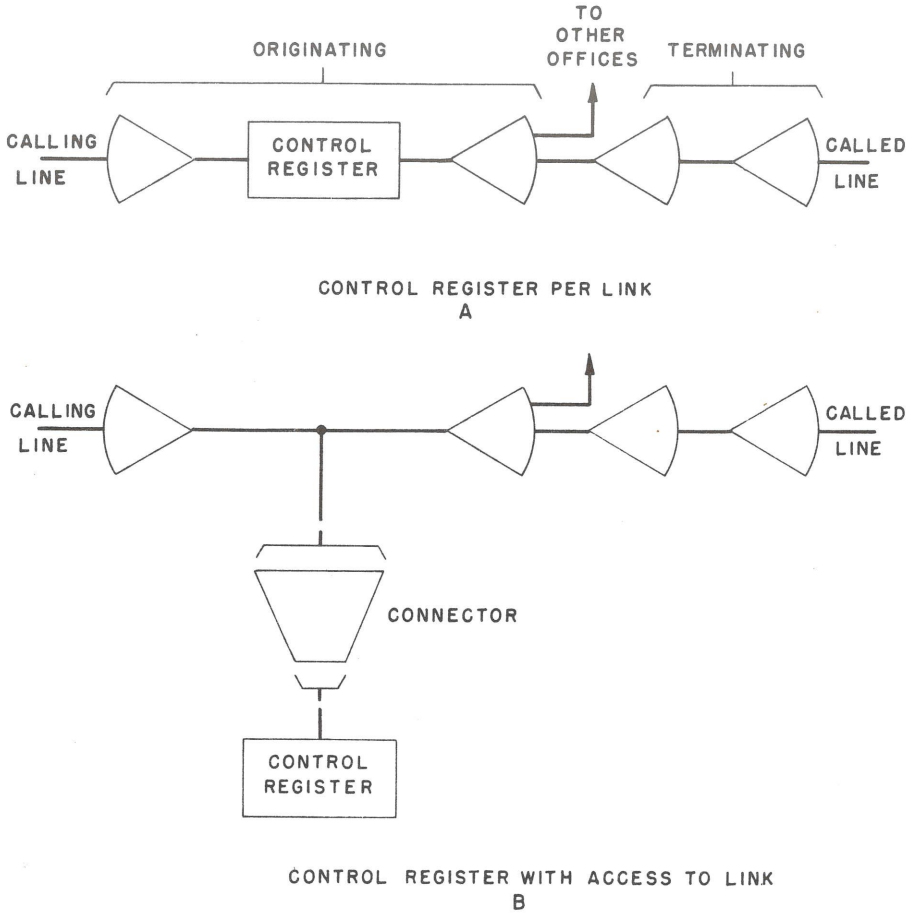


Figure 5-5 Location of Control Register in System

The first-stage links are furnished in quantity sufficient to handle the expected maximum number of coincident originating calls. Since the length of time required for receiving subscriber instructions and establishing a connection is but a fraction of the over-all holding time per call, it is clear that providing a control register per link is unnecessary. For this reason it is worth while to remove the control register from direct connection to the link and instead provide separate access means from all links to a limited group of control registers. This is indicated on Figure 5-5B. By employing such access means, the number of control registers can be held down to whatever is adequate for efficient handling of originating traffic.

From an economic point of view, the cost of providing the access means or connectors must be balanced against the resultant saving in control register

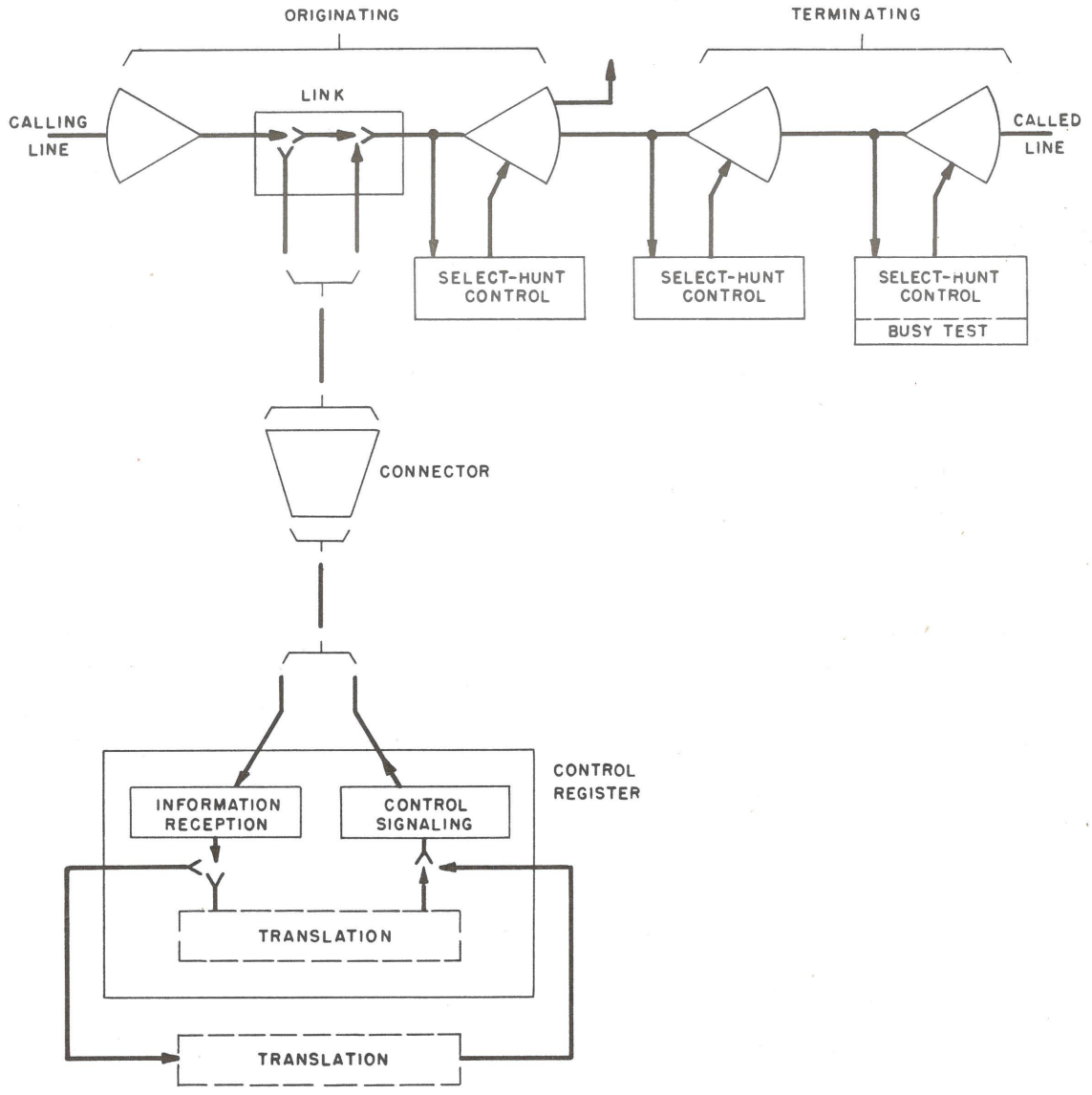


Figure 5-6 Control Register Functions

circuits. Although in this case it is easy to justify the use of connectors, this factor must always be considered when common equipment is introduced into a switching system. If a register of sufficient simplicity and cheapness is available or can be designed, there may be advantages to associating it directly with the subscriber's line, either at the central office or on the subscriber's premises. For the present, however, the location of the control register within the system will be assumed to be that shown on Figure 5-5B. The form of the access means and its control will be discussed in a later paragraph.

A more detailed picture of the control register and the network is shown on Figure 5-6. When a subscriber lifts his receiver to originate a call, control means (not shown on Figure 5-6) must connect the subscriber to a link and the link to a control register. At the same time, the link must be split so that information into and control signals out of the control register do not interfere. Since there may be delays in setting up these connections, either because of competition between subscribers for line finders or a temporary busy condition of links or registers, a signal must be given to the subscriber when the register is prepared to receive his instructions. This signal is the dial tone.

The three basic functions of the control register are information reception, signaling means for control of the switch network, and translating means for converting the received code into a new form suitable for use by the control signaling means. Since these three basic functions make the subscriber's calling device completely independent of the switching network, there is immediate possibility of improvement in range, speed, and type of subscriber control signaling. As the instructions from the subscriber are received, in whatever form the system provides for, the information receiving circuit accepts and registers the directory number of the called line. The directory number identifies, first, the trunk group to the desired central office and, second, the called line in the central office. This, in the general case, requires two separate translations. In order to speed up service, it is desirable to translate and utilize the incoming information as soon as sufficient digits are registered. For example, if three digits comprise the office code, as soon as these are registered, translation and selection of a trunk can take place while the line code is still being registered.*

On Figure 5-6, the translating means of the control register is shown in two alternative locations. Since the translation process occupies but a short period of the over-all holding time of the control register, if the required equipment

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*In order to clarify this discussion, the following example derived from the Panel Switching System is presented. The switching mechanism of the first selecting stage consists of a selector rod with access to five banks of 100 terminals, each bank divided into 10 groups. A particular trunk group corresponding, say, to the Chelsea 3- office may connect to the terminals in the sixth group of the fifth bank. When the subscriber dials CH 3, the numerical code 243 is recorded in the control register. The translating means converts 243 to an equivalent code 4-5 representing fifth bank, sixth group, the code numbering starting with zero. The control signaling part of the control register thereupon causes the first-stage selector rod to select the Chelsea 3- group of trunks by a process which involves the selector rod moving over the terminals and signaling back to the register its instantaneous position. When the selector rod brush has reached the correct trunk group, the register stops the selecting action.

is sufficiently large and expensive it may be desirable to provide separate translating units with access from the control registers. This subject is covered more fully in the paragraph on Translation. For purposes of the present discussion, the translation means can be considered either as an integral part of or external to the control register.

The control signaling means of the control register is designed to function with whatever control technique is required by the switching devices. Since the network is of the progressive type, consecutive sets of signals must be employed to control each successive switching stage. The character of the individual sets of signals is dependent only upon the switching device, and in general need bear no relation to dial pulses. As in direct progressive control systems, circuits capable of responding to control signals and, in the intermediate stages, of performing the hunting action must be associated with each network stage as shown in Figure 5-6. Since complete information as to destination remains stored in the register, hunting time is not restricted to the interdigital time taken by the subscriber while dialing and the size of hunting groups can be made as large as necessary. To take full advantage of this, the switch control means associated with each switching stage must be able to inform the control register when it is ready.

In the discussion thus far it has been tacitly assumed that the call remained within a single central office. In the general case, the central office is part of a network requiring intercommunication between all offices. If all offices employ the same switch control technique, the picture presented on Figure 5-6 is adequate for interoffice connections since the terminating networks into which all outgoing trunk groups feed will be identical. The control signaling from the originating office control register can be the same in all cases except, perhaps, for the transmission level of the signals. The signaling transmission level, however, can easily be controlled by the translator as a function of the office code. If line number translation varies from office to office, the picture is complicated somewhat. Although it is conceivable that the translating means at the originating office could make an over-all translation of office and line code, in general this is impractical. The two alternatives are (1) employ a fixed relationship between directory line number and control signal code, thereby permitting all originating offices to use the same translation, and (2) furnish control registers with associated line number translators at the terminating end of each office. In practice, as will be discussed in the paragraph covering Translation, the first alternative is usually taken.

When some or all of the central offices surrounding an office of the register controlled type employ different control techniques, interoffice signaling can most easily be taken care of by modification of the control register. This involves adding to the control register an information transmitting function capable of sending out whatever type of signal is required by each terminating office. For example, if the call is to a manual office, after the trunk has been chosen the control register can transmit the line number in the PCI code discussed in Chapter 7. If the call is to a direct progressive control office, dial type pulses can be transmitted by the control register.

The control register with the information transmitting function added is shown on Figure 5-7. The translation means determines from the office code not only the location of the outgoing trunk group, but also the type of output signals required and the amount of information to be transmitted. Since the translator permits adjustment of output signal level as a function of the office code, large variations in interoffice distances are more easily taken care of than in systems which employ direct control. The net effect of employing control register units of the type shown in Figure 5-7 is a great improvement in the scope and flexibility of engineering in areas involving many central offices.

Figure 5-8 illustrates some of the flexibility inherent in register-controlled switching systems. On an originating call, as described previously, the control register can determine by means of translation the location of the outgoing trunk group and the type of out-signaling required. Since the office code translation can be flexible, the trunk group can be placed on the switches in accordance with group size and availability of space on the switches, all translators being set up accordingly. Either one, two, or in some cases, more switching stages can be employed for the outgoing trunk group selection with the translator determining the control signaling necessary in each particular case. Some calls may be routed through tandem offices of the type illustrated in the enclosed block on Figure 5-8. When this is done, the translation will require the control register to transmit complete information including office code so that trunk selection may be made at the tandem office. In general, the tandem office will employ control registers which accept the information from the originating office and thereafter direct the progress of the call through the tandem selecting stages and the terminating network of the called office.

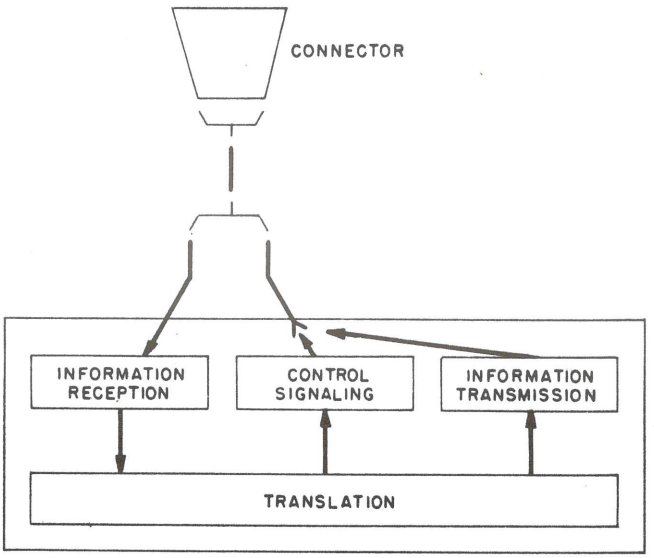


Figure 5-7 Control Register for Interoffice Use

Incoming calls to the office, if originating in a similar type of office, can be handled directly under the control of the distant office. This is indicated by incoming trunk A on Figure 5-8. However, if the originating office employs a different type of signaling, as might be true from a manual or direct control office, incoming control registers accessible to the incoming trunks can be provided. This is shown by incoming trunk B on Figure 5-8. These control registers function in a manner similar to the originating control registers requiring, however, only the line number and not the office code.

A new possibility opened up by the introduction of control registers is alternate routing. This is exploited in a multioffice network in which offices are connected both by direct trunks and trunks through tandem. On a call to an outside office, the translating means will first provide for selecting the direct route to the office. If all direct trunks prove busy, the translator can, since the office code remains stored in the register, furnish a second translation which guides the call through tandem trunks. In systems employing the progressive type of switching network, the alternate routine process is time consuming and increases holding time when the office is most heavily loaded. Therefore it may not prove practical unless the trunk busy test can be made prior to path selection. Nevertheless, the principle is extremely important and is put to widespread use in register systems employing common control. In the ultimate, in toll systems for example, several alternate routes can be made available.

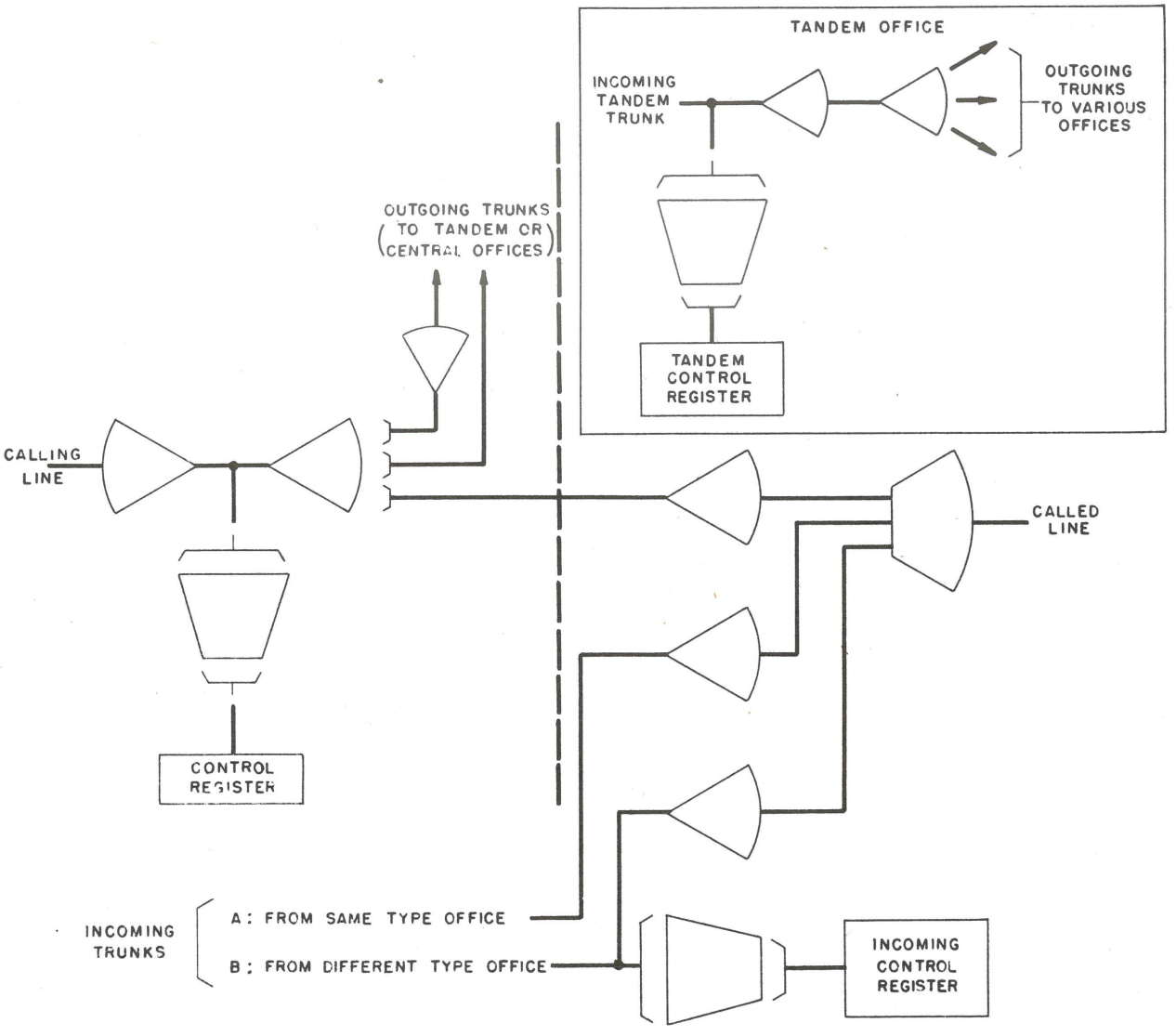


Figure 5-8 Control Register in Interoffice Trunking

Related to alternate routing is another feature made possible by the use of register circuits and generally known as second trial. If a path through the switches cannot be established, either because of busy links or trouble conditions, the control register can abandon the first attempt and start again, utilizing different circuit components where possible. Again, as in alternate routing, full use is generally not made of this feature in progressive network systems because of the time factor.

In register progressive control systems the factors affecting the switching functions of busy-testing, alerting, attending, and so forth, are similar to those obtaining in direct progressive control. There is somewhat more freedom in locating the auxiliary supervising function since, until the connection is finally established, supervision is concentrated in the control register which can temporarily hold each successive switching stage as it is added. Thereafter, supervision can be turned over to circuits located at any stage in the network. Since there are some advantages in having close association between the control register and the circuits which later pick up the supervising function, the link ahead of the first selecting stage is a good location. This forward-holding position is also good from the standpoint of requiring the minimum number of circuits.

Incoming trunks from other offices also require supervisory means. This, in general, could be placed at the input stage or the final stage, but is usually located at the former position. In theory, on intraoffice calls, only one supervisory circuit is required for each connection. In practice, however, particularly where there is a high percentage of interoffice traffic, it is desirable to provide supervisory means at the terminating end of intraoffice trunks in addition to the means located in the first link. This makes it unnecessary for the first-link supervisory circuit to differentiate between calls to the same or another office.

Translation

In Figure 5-6 two alternative locations of the translating means for the control register are shown. The external position, of course, implies that a common translator can be utilized by several control registers. There are several factors which control the choice of individual or common translators, the chief of which are (1) the size and cost of the device, and (2) the frequency with which changes must be made in the translatable information.

The two translations that must be made, and these are essentially independent, are line number translation and office code translation. The case for each will be taken up separately.

Flexible, or variable translation from line directory number to line equipment location on the boundary of the switching network may be of benefit in two situations: first, where traffic becomes abnormally heavy to a number of lines served by a particular group of final stage switches; and second, where a group of lines serving a single subscriber* outgrows the available terminals at a particular

*PBX (private branch exchange) trunks—see Chapter 10.

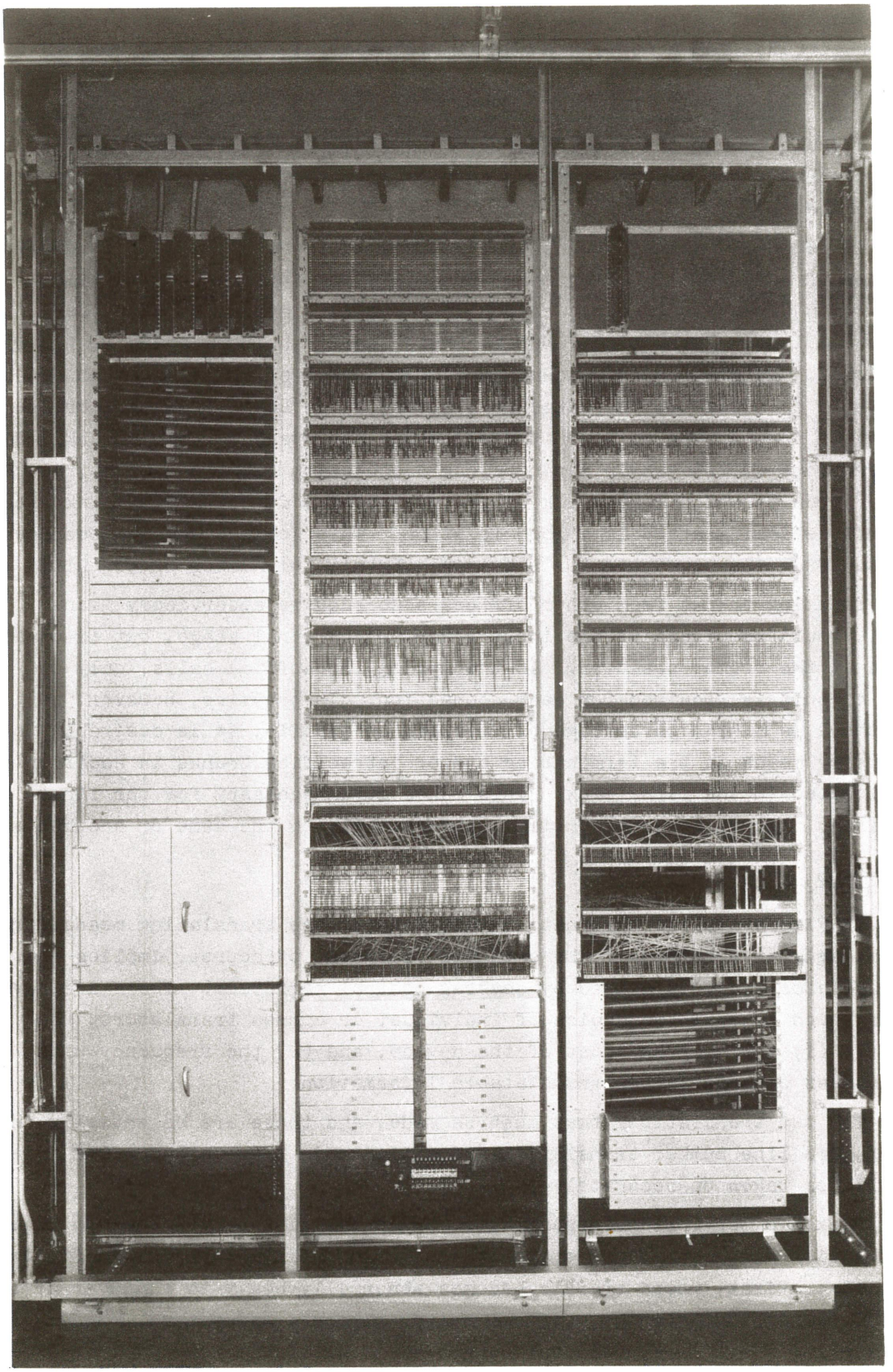


Figure 5-9 Relay-Type Translator With Cross-Connection Fields

final stage The first situation can be taken care of in progressive type networks by adding switches to the final stage group or, if necessary, to preceding stage groups to enlarge the traffic handling capability of the overloaded group. The second is more difficult without freedom of line reassignment, but trouble can be minimized by initial adequate forecasting of subscribers' needs.

The disadvantages of flexible line number translation are overwhelming in comparison with the minor advantages. Either separate translation for all central offices within an intercommunicating region must be furnished at the originating end of every office, or registers plus translation equipment must be provided at the terminating end of each office. The first option is not only expensive, but is difficult to administer since a line change in any one office requires immediate change of translating information in all connecting offices. The second option requires a considerable amount of expensive equipment which is necessary, in general, only to provide flexible line translation.

For these reasons it is customary to have a fixed line-number-to-equipment-location-translation in register progressive control systems. The translation can be wired directly into the control register and requires a minimum of maintenance effort and expense.

The advantages of flexibility in office code translation are much more clear-cut than is the case with line number translation, particularly since the problem is local to each office. All offices in a multi-office area have individual trunking problems, depending upon their specific interoffice and intraoffice traffic. For example, in most offices, at least where the community of interest is localized, the intraoffice trunk group is larger in size than any particular out trunk group except, perhaps, for tandem trunks. It is desirable, therefore, to place the intra-office trunks in each office in the most advantageous position on the switching frames from the point of view of speed of selection. This, of course, is impossible when the office code bears a fixed relationship to the switch location of the trunks. Furthermore, the balance among trunk groups is constantly shifting as new offices are introduced into an area, new business centers appear, residential areas change in popularity, and the like. When a trunk group grows beyond the available terminal space in one location, it is then desirable to be able to shift it to a new position on the switching frames or interchange it with another group. It is also worth while to be able to provide a variable number of selections for the different trunk groups as illustrated on Figure 5-8.

Such flexibility can be attained by translation means which include relay circuits with cross-connection fields allowing for semi-permanent wiring, or with punched cards read by light beam-photocell techniques, or with multi-element gas tubes with simplified cross-connections, and so forth. In most common use in local switching systems at the present time are relay circuits with cross-connection fields. An example of this type is shown on Figure 5-9.

Such translating devices are complex and expensive and generally can not be justified on a per register basis. Furthermore, since there may be more than a hundred control registers in an office, there would be obvious difficulties in

making even a simple change in translation information. However, it has been mentioned previously that translation occupies but a small portion of over-all register holding time and therefore it is practical to disassociate the office code translator from the individual registers and provide a small common group of translators. This arrangement is indicated by the external translation on Figure 5-6 and requires, of course, access means between all control registers and translators.

In addition to providing information on switch selections to the control registers, the office code translator, or decoder as it is frequently called, can conveniently supply whatever other information is necessary for the handling of the call. Such information includes the type and level of signaling required for completion, whether the subscriber is entitled to make a particular call and, if not, the appropriate disposition, and alternate routing selections.

Register and Translator Access

Since access means between the switching network and control registers and between control registers and translators is a necessary concomitant of such common equipment, great care must be exercised to make the access means as efficient as possible. Otherwise the advantages of the common equipment may be overbalanced by the cost of the auxiliary connecting equipment.

The problem of access between the switching network and the control registers is characterized by the following considerations: (1) a large number of points in the switching network (of the order of one thousand) must be connectable to a moderate number of control registers (of the order of one hundred); (2) a small number of leads per connection, approximately six or eight is necessary; and (3) the time taken to establish the connection must be appreciably less than control register holding time to keep down dial tone delay.

These general considerations permit the use of switches for connecting purposes rather than requiring high contact carrying devices like multicontact relays. The connecting network itself is similar in principle to the concentration stage of the main switching network. Although single-stage connecting is possible, with the switches facing either the access points in the network or the control registers*, a two-stage connector based on the link principle is considerably more efficient in number of switches required to give equivalent service.

The link type of connector is illustrated on Figure 5-10. In the general case it is satisfactory to let the input side of the connecting link face a fractional part or a group of switching network access points. The size of the group may be determined by the individual access of the switching device or by other equipment factors. However, the output side of the connecting link should give access to all registers if possible, since subdivision of the latter tends to reduce the efficiency of their use. Since holding time of the registers is appreciable and more than a slight delay in establishing a connection cannot be

*These are similar to the line switch and line finder techniques discussed in Chapter 4.

tolerated, several links per input group must be furnished. The precise number depends upon the size of the input group, calling rate, average register holding time, and the grade of service desired. In order to keep low the over-all number of links, the input group size should also be as large as possible. Unless there is no grouping of inputs at all, the total number of links must be greater than the number of registers in order that idle registers shall not be blocked from service by a lack of idle links within a particular group. If switch size does not permit full access to all registers, the register groups should be distributed over the several links in a link group so that the over-all access of the latter may be as great as possible.

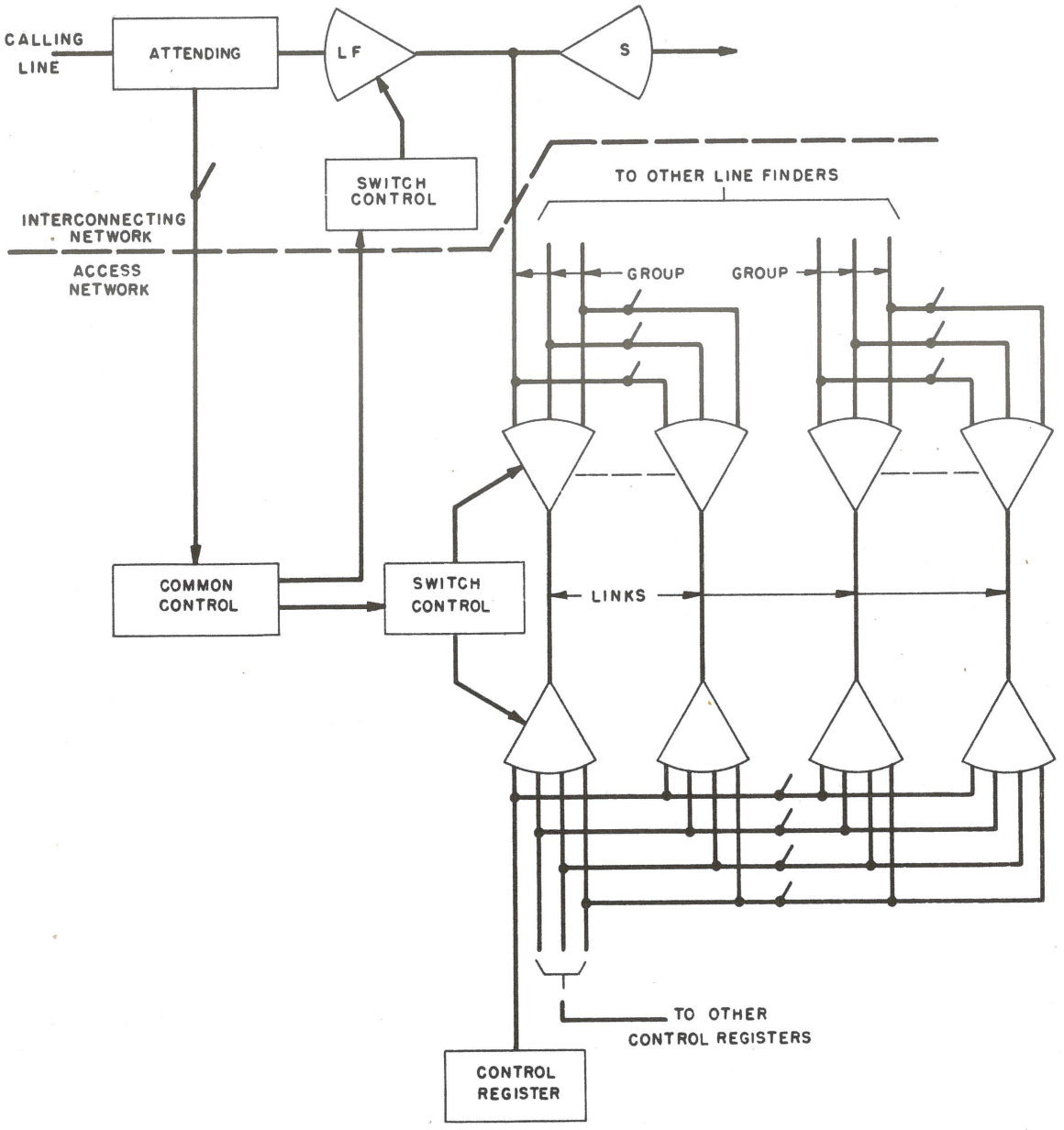


Figure 5-10 Access Network for Control Registers

It is inherent in this connecting problem that common control must be utilized. Also, this common control must be intimately associated with that employed to activate the switching network line finders as described in paragraph 5.2. If mechanical type switches are used for line finding and connecting, it is not desirable, because of time limitations, to permit the two register link switches and the line finder switch to wait for a service request before starting their action. It is preferable, rather, for the control means to cause each register link input switch, as soon as it becomes idle, to hunt for and connect to an idle line finder. The control means can then pre-allot such an idle line finder register link pair to be ready when a service request appears. If the switches do not provide full access from each register link to all registers, the control means must allot to a call only a line finder-link pair with access to a register group including idle registers. Preallotment of registers is of doubtful benefit since they are accessible to several link groups and allotment in one group must not make them busy to other groups. However, some advantage can be gained by not moving the register link switch from the register terminals when the latter circuit becomes idle. In this way the register link switch need hunt only when the register is reseized elsewhere before the next link usage.

The present discussion of register access means has been predicated upon one type of input subscriber's line and one type of control register with full freedom of interconnection. In the general case of several types of lines (or incoming trunks) each requiring access to a particular type of register, modification of the access plan is necessary. There are two principal ways of handling this situation. In one, the associated types of lines and registers are segregated with specific link groups assigned to each class. In the other, the lines and registers of the different classes are intermingled, but the attending function associated with each input gives a class indication to the control circuit which specifies the type of register required. The control circuit then locates the correct type of register and establishes a connection to it.

The problem of providing access between control registers and translators is also best solved by a link type of connector. However, the considerations that apply to the translator connector are somewhat different from those listed for the control register and result in a modified form of link access. These considerations are:

(1) a relatively large number of registers (of the order of one hundred) must be connectable to a small number of translators (of the order of ten or less);

(2) a large number of leads per connection, of the order of one hundred, is necessary;* and

(3) delays in establishing the connection may be of the order of a translator holding time or more since the holding time is very short and the subscriber is affected only indirectly by the delay.

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*This assumes the type of translator in which a large amount of information is transmitted simultaneously over many leads rather than consecutively in time over a few leads.

The large number of leads required per translator connection disqualify the usual multioutput switch device as a connecting means and necessitate use of multicontact relays. Since the relays have only two positions, open or closed, several of them are necessary at each end of each link and a link becomes an expensive item. However, advantage can be taken of the fact that delay of the order of several translator holding times is permissible by providing but one link between a group of registers and the translating circuits. This is shown on Figure 5-11. The maximum number of registers in a group is determined by the average holding time, the calling rate for translators and the allowable delay. It is preferable, of course, to provide full access to all translators from each link.

The control means for the register-translator connector is usually more complicated than for the connector to the registers since relays are used for access instead of switches. In effect, the job of guaranteeing exclusive connection at each end of the link, inherent in most types of switches, is turned over to the control circuit. The control means of Figure 5-11 must recognize a request from a control register, permit only one register at a time to have access to the link, give access from the link to an idle translator, and at all times prevent double connections. This is a difficult switching job.

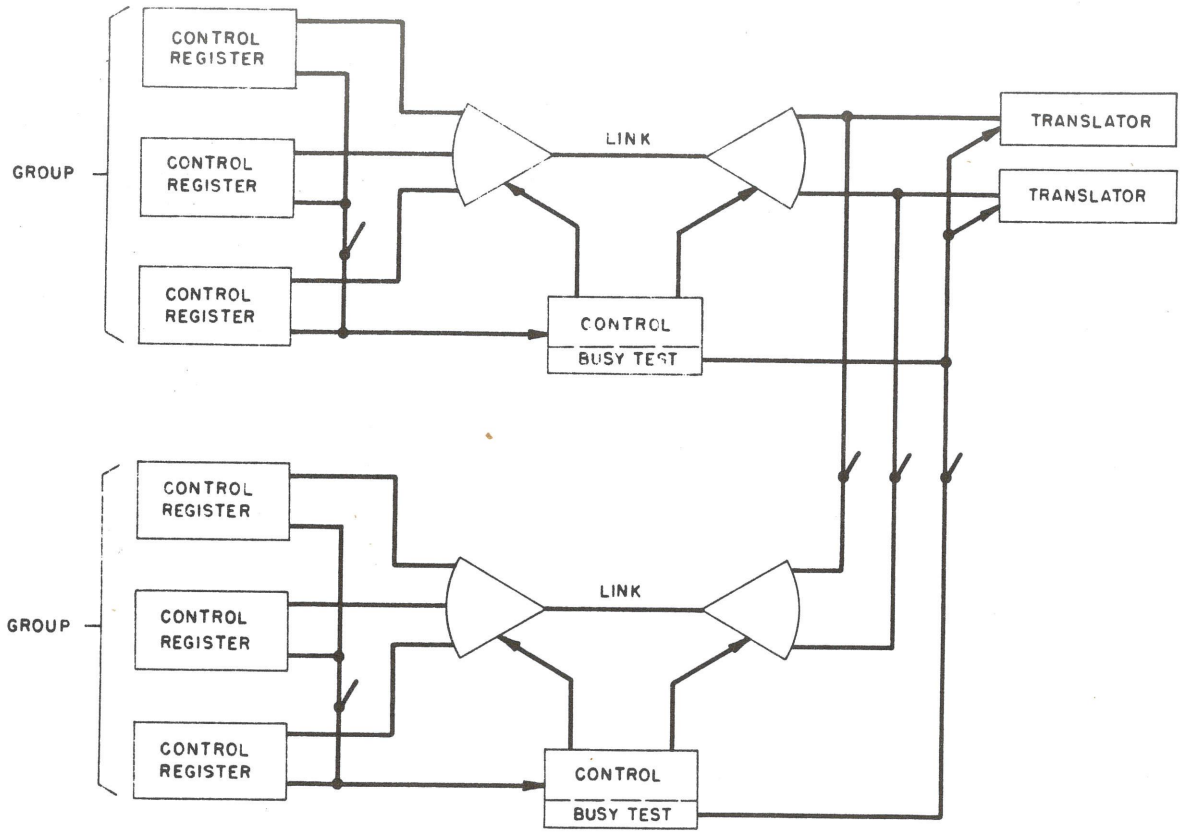


Figure 5-11 Access Network for Translators

Conclusions

The introduction of control registers with associated translating means vastly improves the scope and flexibility of progressive type switching systems. Switches with greater speed and access than is possible in direct control systems permit more efficient networks for large-size offices. The trunking flexibility permitted by register control is almost a prerequisite in metropolitan multi-office areas. Coupled with trunking flexibility is the possibility of alternate routing and second trial which can improve the efficiency of the outside cable plant and give better subscriber service. Since all interoffice signaling originates in the control registers instead of at the subscriber's premises, increased range and speed of signaling is possible and control signal repeaters are unnecessary. Calls through several switching points of different types are feasible with selections and signaling determined at each successive point by registers and translators.

Since the subscriber's calling device is independent of switch control, independent improvements in either become possible. It is worth noting, however, that if such improvements are not made, service through a register controlled system is slower than through a direct controlled system. With direct control, the last pull of the dial establishes the connection, whereas, with register control, new control signals must be transmitted to the switches subsequent to the last pull of the dial.

The chief disadvantages of register progressive control stem from the utilization of the progressive type network. With present day equipment the establishment of a call through a progressive network is relatively slow so that full use of alternate routing and second trial is inhibited. Since it is generally most economical in calls between offices with progressive networks to transmit the switch control signals themselves from the preceding office, rather than to transmit only the required information, interoffice signaling tends to be limited in range and speed. Most of these difficulties are overcome by common control techniques discussed in the next chapter.

5.5 REFERENCES

Direct progressive control systems are well exemplified by the various step-by-step telephone switching systems. These are described in some detail in Out-of-Hour Course Text 162—Step-By-Step Dial System, and in briefer form in Out-of-Hour Course Text 265—Telephone Switching Systems, Part II. The Panel machine switching system is the best example of register progressive control and is described in Out-of-Hour Course Text 163—Panel Dial System, and in Out-of-Hour Course Text 265—Telephone Switching Systems, Part III.

CHAPTER 6

SWITCHING SYSTEM PRINCIPLES, PART IV—COMMON CONTROL

6.1 INTRODUCTION

The term "common control" in switching can be defined both as a circuit technique and as a switching system principle. Although it is the system connotations of the term that are of primary interest in this chapter, these aspects must of necessity be related back to the circuit considerations. As a circuit technique, the term common control implies the use of control means common to more than one switching device. As such, common control is utilized in register progressive control systems for establishing paths through the concentrating switching stage and through the register and translator connectors. In the same sense, the control register itself may be considered a common control device.

Following this line of reasoning to its logical conclusion, any system which utilizes common control techniques in all or a majority of the switching stages could be characterized as a common control system. For example, a progressive system in which control circuits are used in common by switch groups at each stage falls within the meaning of the term. However, establishing the extensive use of common control techniques as the definitive requisite of a common control system opens up a great many possibilities of different system configurations. On this basis the development of fundamental system principles applicable to all common control systems would be difficult. It is therefore advisable to restrict the discussion to common control systems of the greatest current significance.

At the present time the most important system-wide application of common control provides for a control means, common to the interconnecting network, which first identifies the input and output terminals of the network and thereafter sets up a connecting path between them. The whole central office interconnecting network may be handled as an entity, or it may be divided into originating and terminating halves with separate control means for each half. It is solely with this widely accepted type of common control system that the present chapter is concerned. In this respect, it is convenient to designate common control systems in this category as marker systems in order to differentiate them from systems which employ more generalized common control techniques. If the control means is a

separate and distinct circuit unit, it, in turn, may be called a marker.* To avoid confusion, these terms will be used throughout the chapter to represent the system and the interconnecting network control means. Where subsidiary common control means are required for purposes other than establishing transmission paths through the network, the general term "common control" will be used.

In discussing marker systems, it will be assumed that the interconnecting network is of the grid type developed in Chapter 4. The grid type network not only requires by its nature the use of common control, but at the present time is the most frequently used interconnecting method employed in marker systems.

It will be recalled that the grid network in its most usual form is composed of two or more stages of primary-secondary grids. The characteristics of this network are such that, if an input and an output are specified, sets of linkage paths exist which can be matched together to provide a group of channels between the terminal points. It is the function of the marker to identify the terminal points on the grid, locate and test the group of channels, and finally set up a particular channel through the switches. The principles developed in discussing this specific control problem should be applicable in general to common control techniques required by other types of network.

With grid type networks it is often unnecessary to differentiate between the concentration—expansion stages and the distribution stages since the former can be incorporated in the latter by the building out process described in Chapter 4. For this reason, the primary discussion in this chapter will concern itself with control of the grid network per se with no separation of the parts except into originating and terminating networks. However, a final paragraph will take up the control of concentration and register access stages since some systems require such separate action.

One of the basic principles of marker systems is that the register is always necessary. Since one of the chief requirements of common control is high speed, it is uneconomical to permit the holding time of control units to be dependent upon the vagaries of subscriber dialing habits. Therefore registers, located either within the central office or on the subscriber's premises, are necessary in marker systems. These registers, unlike those in register progressive systems, need not incorporate control functions but merely store information from the subscriber or a distant office.

6.2 NETWORK CONTROL

On Figure 6-1 is shown a schematic representation of an interconnecting network and its associated common control means or marker. For the time being the central office network is considered to be split into separate originating and

*The term marker derives from the circuit function of "marking" or placing a distinctive electrical condition upon a switch terminal as a means of directing the switch to that terminal. In practice, marking may consist merely of identifying the network terminals to which a connection is to be made.

terminating halves, and the network of Figure 6-1 may represent either half. If it is the originating half, the inputs are subscriber lines or concentrated links connecting from the subscriber lines, and the outputs are trunk groups. If it is the terminating half, the inputs are incoming trunks (perhaps from the same office), and the outputs are subscriber lines. In any case, associated with the inputs are registers which receive the call information and which have access to the marker. Access from the inputs to the registers can be achieved in a variety of ways, either through separate connectors or through the main interconnecting network. For the time being, unspecified access will be assumed.

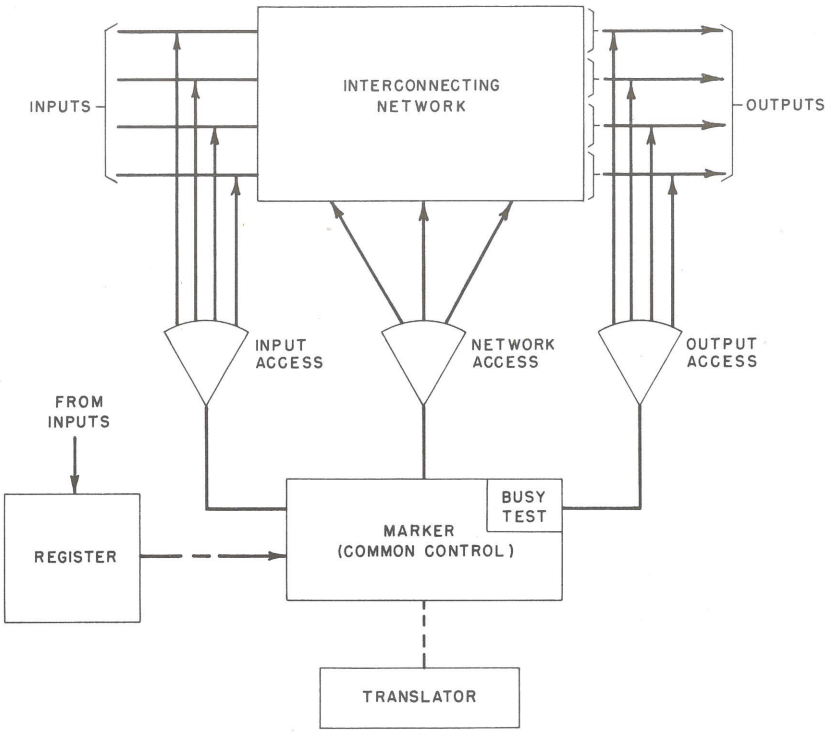


Figure 6-1 Generalization of Marker System

On an originating call, the register must receive information from the subscriber before it can utilize the services of the marker. In the general case the office code is sufficient to identify the required trunk group, and, as soon as it has been received, the register can request the marker to set up the connection between line and trunk. When access is established between register and marker, the register transfers to the marker the office code together with information as to the location of the calling input. Since this latter information is used for control purposes, the register may either incorporate means of determining calling input location for use by the marker, or it may provide a path from the marker to the input via which control can be exercised.

For reasons discussed under register progressive control systems, it is highly desirable not to have a fixed relationship between office code and trunk location on the switches. Furthermore, the nature of great networks almost necessarily precludes such a relationship. Therefore, when the marker receives from the register the office code, it determines by translation how to gain access to the trunk group, plus any other pertinent information such as type of out-signaling required. Since, with the type of switch units normally used in marker systems, there is no practical way of securing automatic hunting action over adjacent terminals by the switches themselves, the individual trunks of a group can be dispersed

over the whole network with considerable freedom. This, however, requires that the trunk-busy test function be concentrated in the marker and that access means be provided from the marker to the test leads of the trunk group. Since successive individual tests of the trunks would take too much time, the test leads should be grouped for simultaneous testing.

There are several ways in which the marker can determine the location of a particular trunk out of a group, all of which usually imply an orderly pattern in the disposition of the trunks of a group on the switching frames. If the trunks are concentrated on a particular switching frame, the translator can specify the frame, the trunk location pattern, and the test lead group. The control circuit can then set up the appropriate access paths for the test leads, pick a particular idle trunk, and determine from the position of the chosen trunk in the pattern its specific location. If the trunks are dispersed over all output switching frames, an auxiliary busy test may determine on which frame there are idle trunks and thereafter the control circuit can gain access to that frame to pick a particular trunk. On Figure 6-1 a generalized access to the output groups is shown. This access may include control paths in addition to the testing paths.

At the same time that the marker is locating and connecting to the output terminal of the network, it must gain access to the particular input terminal being served. This access may be over a separate path specified by information received from the register, or it may be through the register to the input point.

As a result of these two actions the marker has control of the terminal points that must be connected together. Depending upon the particular systems, the terminal access may or may not include access to the correct points within the interconnecting network for testing paths and establishing a connection. If not, the marker must interpret from the known input and output locations the correct access paths to set up into the network. When this access has been established, the marker examines the individual network links that match to form a channel and connects together an idle set. It is desirable to examine all links simultaneously, rather than on a progressive basis, in order to save time. An exception to this is provided in certain systems in which the marking of the end points results in idle connecting links automatically building up toward each other at high speed. One of the groups of established paths is then retained and all others discarded. In any case, when the control circuit has made sure that the interconnecting path is set up, and held to a supervisory circuit, it releases and becomes available to other calls.

In order to make somewhat more clear the control technique involved in gaining access to and selecting channels, a block schematic of a scheme applicable to grid networks of the crossbar type is shown on Figure 6-2. Although this is rather a specific example, it may clarify the understanding of the more general discussion. The two grids are part of an over-all network of the type discussed in Chapter 4 and shown on Figure 4-32 and are interconnected with other input and output grids. It is assumed that, prior to the stage pictured, the marker has selected a particular output and has connected itself to the calling input. Both of these terminal

points are indicated on the figure by a check mark. The location of input and output is registered in the control circuit in terms of the grid and switch on which each is located. From this knowledge the marker determines the specific test and control access paths which must be established to the grid switching frames. On Figure 6-2 only the necessary paths out of the large number of possible ones are indicated.

Within the marker the link testing paths, shown as solid lines, are grouped to associate the "A," "B," and "C" links into matching sets so that the channel matching circuit of the marker can determine in which channels all links are idle. One is selected and the channel control circuit transmits the control signals over the dashed access paths to establish the connection. In the crossbar system, these signals consist of simple ground closures on selected leads.

Before continuing, it should be noted that although the discussion up until now has been primarily concerned with originating calls from line to trunk, the same considerations apply to terminating calls from trunk to line. If the terminating network is controlled by a separate marker, a register is again necessary to record the called line number before the control circuit is called into operation.

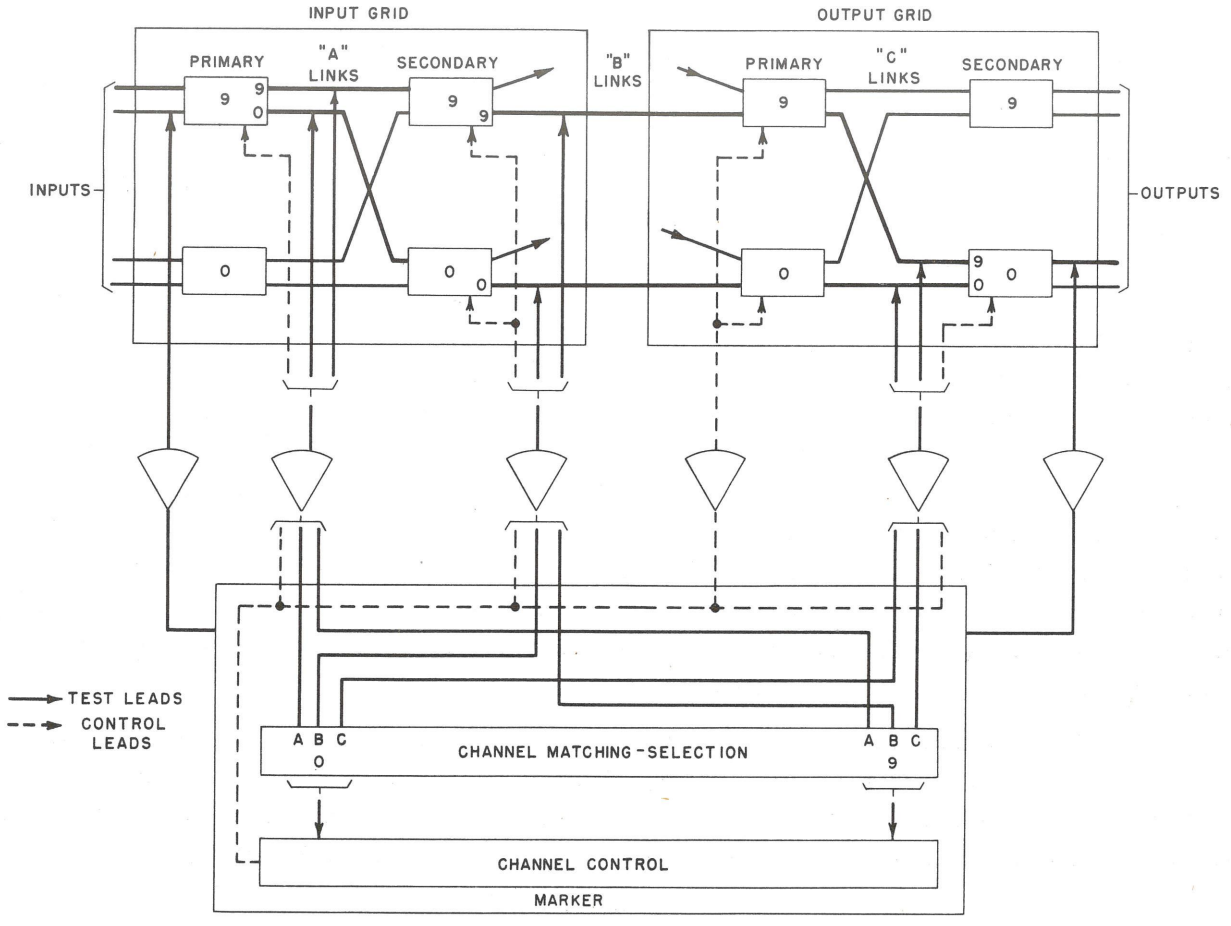


Figure 6-2 Channel Selection

On intra-office calls, this may be the same register utilized on the originating connection. Otherwise it may be a completely separate terminating register. With grid type networks, line number to switch location translation, similar to office code translation, is almost invariably necessary. This comes about, not only because it is difficult to set up a logical relationship between line directory number and switch location with grid networks, but because of the inherent advantages of flexibility. Therefore line translators must be provided by means of which the control circuit can determine the line location from the directory number. This implies that the over-all control of terminating calls is similar to that for originating calls. The principal difference derives from the translation technique which is discussed in a later paragraph. Another minor difference is that, on most calls, a single line rather than a group of trunks is tested. On calls to PBX groups, however, trunk-hunting techniques must be used.

On Figures 6-1 and 6-2 only one marker is shown. This is obviously the most efficient use of the control means, concentrating as it does all test and control features into a single equipment unit. However, in the light of the circuit techniques of today, this constitutes an ideal rather than a practical attainment. Since no more calls than there are markers can be handled simultaneously, the holding time per call of a single control circuit would have to be short enough to enable handling of all calls without unreasonable delay. At the present time an average holding time per call of about one-half second is considered good. Even with this value, the traffic volume of an average office requires the use of several markers.

As soon as more than one marker is introduced into a system, the problems multiply rapidly. Since it must be possible to place a call from any input grid to any output grid, access must be provided from each marker to every grid of the network. With crossbar type switches, a very large number of leads* is necessary to test and establish paths on a single grid, although only a small fraction are utilized on a particular call. A simplified block schematic indicating how the access problem grows with several grids and markers is shown on Figure 6-3. When so many leads are involved, the only practicable method of handling access is to use multicontact relay connectors located on the grids themselves. The connectors can be designed so that control signals cause selection of the individual groups of frame leads applicable to a particular call. A limited number of leads then pass from markers to the connectors on the grids and the fanning out of the leads takes place within the grid frame. Furthermore, much of the connector equipment can be used in common by all control circuits.

It is inherent in most common control systems that only one control unit can work into an individual grid at a time. Otherwise there is mutual interference that may permit double connections or mutilated calls. This requires an elaborate system of lockouts in the connector means to provide exclusive access. A result of

*On a crossbar frame (grid) there may be as many as 1400 control magnets, 200 links, 900 inputs and outputs, to all of which the control circuits must have access.

this is that the markers may block each other in the handling of calls and are subject to delays while waiting for frames to become idle. This, of course, reduces the efficiency of use of the control units. In designing systems care must be taken that such blocking cannot cause complete exclusion between control circuits. For example, if two markers simultaneously require access to the same input and output grid frames and each is able to seize one of the two frames, an impasse exists. This difficulty can be obviated by designing the circuits so that the grid frames must be seized in a definite order (output before input, for example).

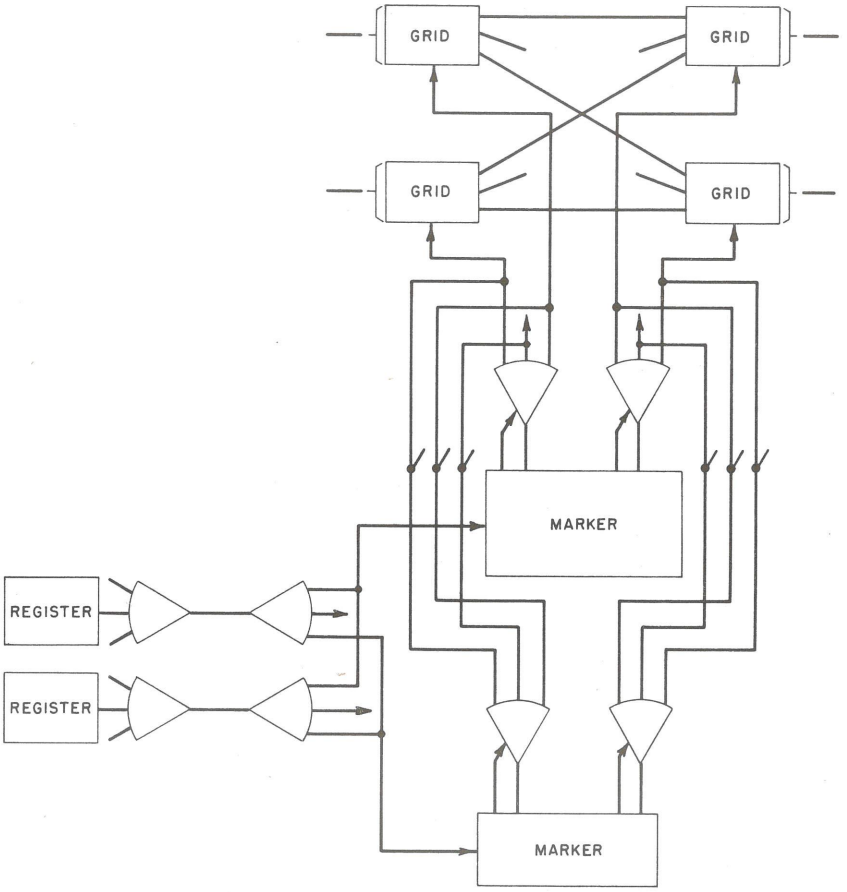


Figure 6-3 Several Markers Applied to A Network of Grids

These considerations, in addition to the fact that marker units are very complex and expensive, make clear the necessity of keeping holding time per call very low. A small holding time reduces the required number of markers with associated access, and increases their efficiency of use.

Marker holding time is to a large extent dependent upon the actuating time of the switches making up the interconnecting network. For this reason common control of the type discussed here is only economical when a high-speed switch mechanism is available. This tends to rule out large-motion switches of the panel or step-by-step type, and to emphasize the use of small-motion (crossbar type) switches or electronic switching means. This statement is only generally true, since high-speed large-motion switches suitable for common control have been developed, but they have not come into use.

The necessity for speed has also imposed the use of fast-acting circuit elements in the control circuits themselves. The present result of this is that common control circuits are almost invariably all-relay devices with some

utilization of electronic tubes. This has a definite effect upon the complexity of control circuits since many circuit functions that are performed very simply, although slowly, by a multi-terminal switch require intricate arrangements of several relays for equivalent action. It can be expected that the use of electronic circuit elements will increase rapidly in the future in order to take advantage of their still higher speed capabilities.

An important aspect of marker systems is that the control circuits themselves must incorporate intricate checking features to insure that they are functioning properly. Since each marker handles a large proportion of all calls served by the office, even a minor trouble in one of them may have widespread effects. Furthermore, the most convenient check of the switching network is by means of the markers which in effect sample the network at frequent intervals. Associated with the checking features should be means for indicating or recording trouble symptoms. The many functions of the control circuit may be so well diversified that trouble which blocks one call may have no effect on another and it is desirable to return the marker to service immediately after making a trouble record.

When a trouble condition serious enough to block a call is encountered by a marker, additional efforts must be made to take care of the call or it will be left hanging in the air, so to speak. Such efforts are, however, faciliated by the nature of common control since the control circuit in trouble can be dismissed by the register and an alternate one selected to make a second trial. The individual markers can be designed to shift preference periodically in choosing frames and trunks so that optimum opportunity is given to the second-trial control circuit to handle the call successfully. In theory it is possible to make an unlimited number of additional trials to complete a call. However, each trial is an extra marker usage which reduces the availability of markers to other calls. Therefore, in practice, additional trials may be restricted to two with the last one consisting of an attempt to set the call up to a tone source which will warn the subscriber to hang up and try again.

When a marker encounters an all-trunks or all-channels busy condition, it also must take some alternative action. Common control is ideally suited for alternate routing (in contrast to progressive control systems) since it tests trunks early in the control circuit cycle before paths are set up. Hence, such systems permit optimum use of direct and tandem trunking facilities. When the control unit determines that all trunks in a particular direct group are busy, with very little additional holding time it can request the translator for directions to an alternate (tandem) trunk group. The control circuit can then handle the call in the same fashion as though it were the original attempt. If there are additional tandem routes available, the alternate routing process can be continued as far as necessary. In local systems the number of alternate routes is usually limited to one or two; in toll systems it may be a great many.

If all usable trunk groups prove busy, the final alternate route, in effect, is to a tone source which can return a trunks-busy or overflow signal to the subscriber. These tone trunks should be provided in sufficient quantity so that there

is little danger of their all becoming busy. However, if the tone trunks are found busy, the system may be arranged either to abandon all attempts or to utilize the still-connected register to return a tone signal. If the subscriber has been connected to a supervisory circuit prior to the use of the marker. Such a circuit also may act as a tone source under these circumstances.

On terminating calls to a subscriber line, if the line is busy there are, of course, no alternate routes except to a busy-tone source. This may be located in a special trunk to which connection must be made or in a supervisory circuit to which the calling subscriber is already connected.

After the marker has picked a trunk or a called line, it may discover a channel-busy condition. If there are alternate channels available, they should be tested as a second attempt. On originating calls to trunk groups, the next recourse is to choose a new trunk in the same or an alternate group which will usually make available a new set of channels. If no free channel is found at all, the call may be handled in the same manner as though no idle trunk or line were available.

6.3 TRANSLATION

It has been mentioned in the preceding paragraphs that in marker systems it is usually necessary to have flexible translation means for both office codes and line numbers. The office code translation problem is very similar to that encountered in register progressive control systems except for the trend toward increased quantity of information required from the translator. This results, in part, from the greater use of alternate routing and the more detailed specifications that are necessary for trunk location. On the other hand, flexible line number translation is not generally provided in register progressive systems.

In the latter type of system the control registers, of which there are many, require the use of the office code translators, and it is impractical to furnish a translator per register. In marker systems, however, the number of control circuits which require translation means is small and it becomes feasible to incorporate individual translating means within each marker. In local switching systems where three-digit office code translation is the maximum used, the translating equipment is not abnormally complex and expensive (in relation to the control circuit) so that there is no great gain in providing separate translators, particularly when the access means required by separate translators are considered. Furthermore, since translator holding time is an appreciable fraction of control circuit operating time, the delays inherent in marker competition for separate translators might require additional markers, thus overbalancing any possible saving. For these reasons the markers which set up originating connections from lines to trunks usually include the translating means. These same considerations do not necessarily apply to toll systems, however, where the added complexities of six-digit translation may make separate translators desirable.

Since the translation and control functions of the marker are essentially independent, some gain in efficiency is possible by providing for overlap operation.

That is, while the marker is engaged in establishing a connection for one call, it may accept another call and perform the translation function for it, thereafter waiting until the first call is out of the way before proceeding with the second.

The information furnished by the office code translator includes the location of the trunk group for immediate use in establishing the originating connection, alternate routing directions, and the type, quantity, and transmission level of signals to be sent to the terminating office. This latter, of course, is not necessary if the call is terminated in the same office and if the dialed information already stored in the register can be used by the same or another marker. However, when the call is directed to another office, or to a terminating register in the same office, the necessary signaling information must be transferred to an information transmission circuit. The latter circuit can be incorporated in the originating register or provided as a separate unit and will be discussed more fully in a later paragraph.

The marker translators, as was true with the register control translation means, must provide full flexibility in furnishing information appropriate to each office code. At the present time the equipment usually consists of relay circuits plus changeable cross-connection fields on which the information for each code can be wired. Changes are relatively simple to make and the number of translator units is small.

The considerations applying to line number translation are quite different from those obtaining for office code translation. The difference is primarily a matter of magnitude since line numbers in one central office run up to 10,000 while office codes are well under 1,000. The resulting size and cost of the line translator is such, with present echniques, that it is uneconomical to provide one per marker. The alternative is to furnish common translating means with access from all markers. If translator cost is not too great, several complete units can be provided in a common group. Otherwise, advantage can be taken of the probability that simultaneous calls will be to lines well distributed throughout the line number series. This permits breaking up one large translator into several parts, each embodying the information pertinent to a grouped fraction of the lines. Each marker must have access to all subdivisions of the translator and, in general, the access must be exclusive to prevent mutual interference. This is the plan followed in present-day marker systems where the translator is known as the number group.

A sketch of this arrangement is shown on Figure 6-4. For convenience, each translator subdivision is shown as comprising 1,000 lines, although this number may vary from system to system depending upon traffic considerations and the particular translation method employed. It is also necessary to employ within the marker some form of pre-translation, usually simple, to determine the particular translator subdivision to use.

It is desirable to perform the line busy-test via the translator as shown by the dashed lines on Figure 6-4. This saves marker holding time if the line is busy since it eliminates the otherwise necessary connection to the grid frame on which the called line is located. When dealing with PBX trunk groups, it is almost

obligatory to perform the busy test in the translator because the individual trunks are usually scattered over several frames. There is also some advantage in making the called line busy through the translator in order to prevent stealing by another control unit, although this may be difficult to achieve in practice.

In addition to called line location and PBX hunting directions, the translator must also furnish to the marker information on the type of ringing required. This is later used to set up the alerting function associated with the interconnecting path to send out the correct ringing signals to the called subscriber.

6.4 INFORMATION TRANSMISSION

Although information transmission has been mentioned previously in this chapter, the specific relationship of this function to the rest of the system has not been discussed. The function is, of course, always necessary for communication with other offices and, in some systems, with the terminating end of the same office. It might be inferred that in many cases the function of information transmission could be incorporated in the marker, assuming that a high-speed signaling system were available. However, if the information reception means at the terminating point is a common circuit and is subject to connector delay (the usual situation), this plan is not practical. There is too great a possibility of an undue increase in the holding time of the originating marker. Furthermore, low-speed signaling to other offices of different types is often necessary and this is a controlling reason for not including the information transmitting function in the marker.

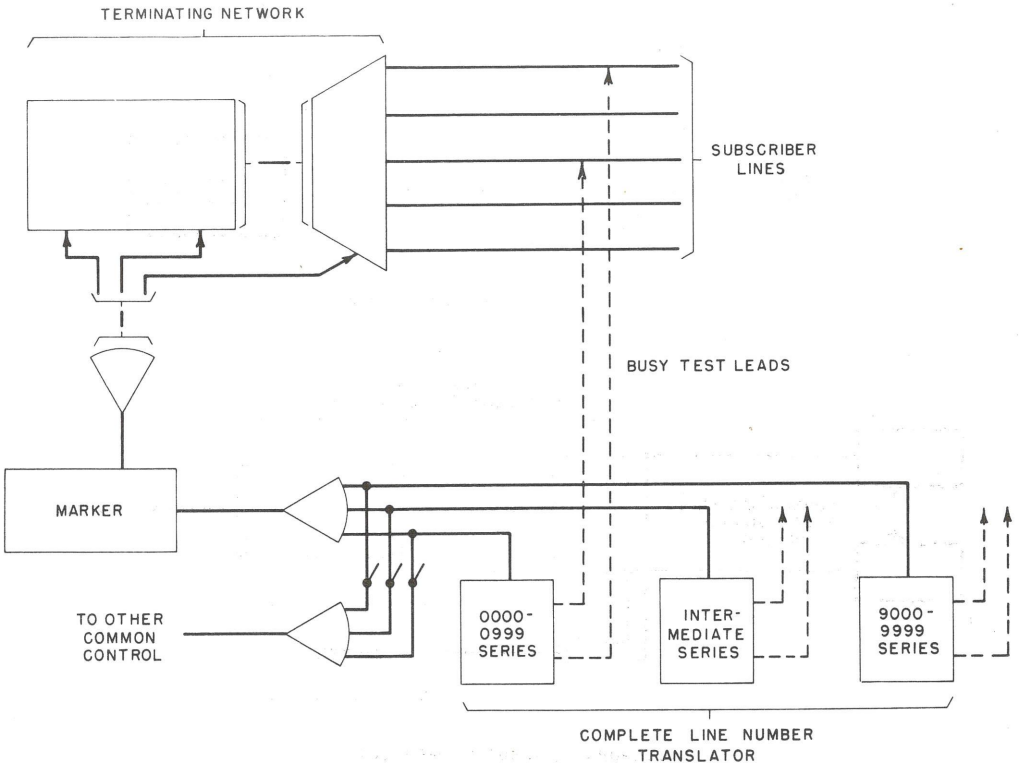
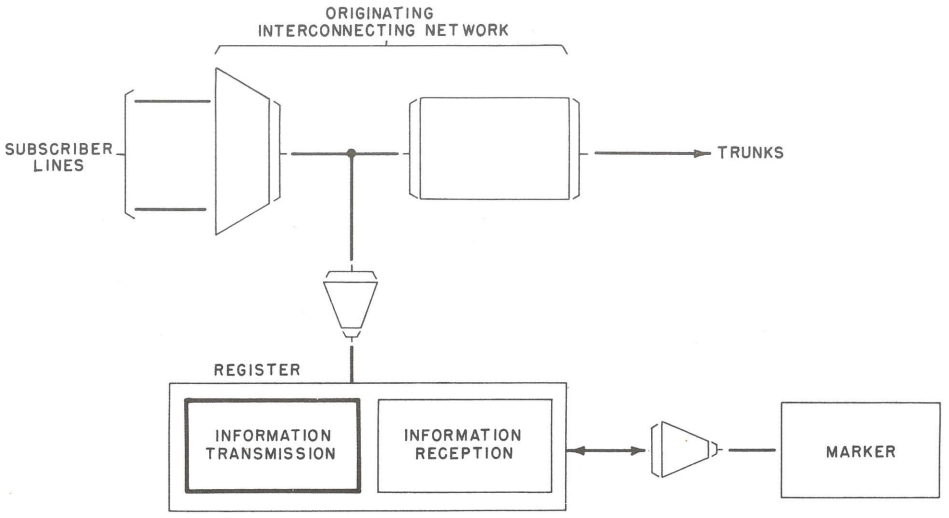
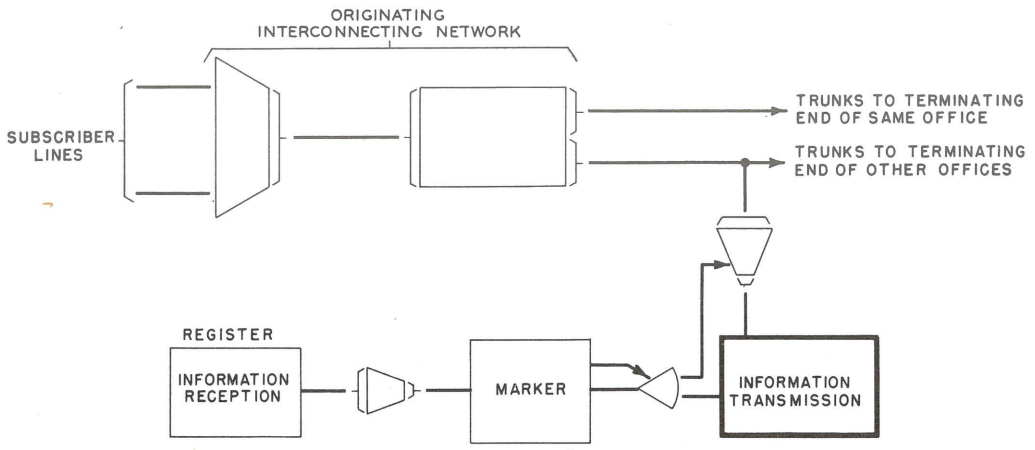


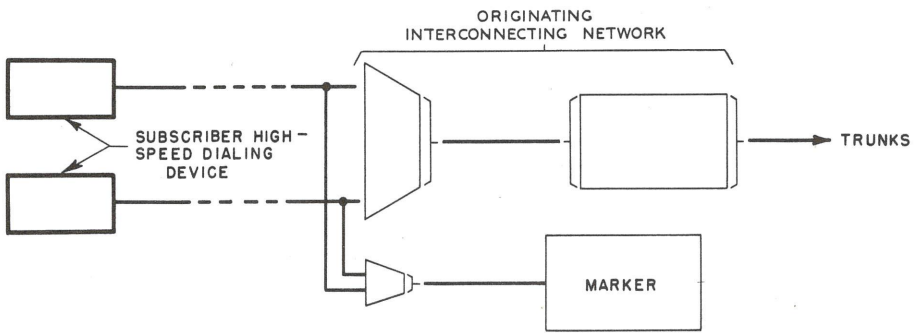
Figure 6-4 Line-Number Translator in Marker Systems



A ASSOCIATED WITH REGISTER



B ASSOCIATED WITH TRUNK



C INCORPORATED IN SUBSCRIBER'S SET

Figure 6-5 Location of Information Transmission Functions in Marker Systems

In systems where separate registers and markers are provided for terminating network control, information transmission is necessary on all calls. It is therefore economical to combine the subscriber register and the information transmission function into a single circuit unit and provide access to the interconnecting network as shown on Figure 6-5A. This is similar to the plan employed in register progressive control systems. The marker, following translation, can inform the information transmission means over the access paths as to the type of signaling required, the number and code of digits to be sent and the appropriate transmission level for the signals.

When the over-all system plan provides for a single type of marker for both originating and terminating network use, information transmission is not necessary for intraoffice calls. In systems such as this, particularly if the proportion of intraoffice calls is high, it is inefficient to incorporate information transmission means in the subscriber registers. A better plan is to provide separate information transmission circuits with direct access to the outgoing trunks as shown in Figure 6-5B. These circuits may be of one general-purpose type incorporating several signaling methods or may be of one or more specific types, each designed for a particular signaling technique.

With the plan of Figure 6-5B, when the marker determines from the office code translation that a call is to another office, it must establish connections from an information transmission circuit both to the chosen trunk and to itself. Over one path the marker informs the information transmission circuit of the number, code, and the like to be transmitted. Over the other path the information transmission circuit transmits its signals as soon as it is assured that the local channel between subscriber and trunk is established and that a register is connected at the distant end.

A third method of interoffice communication depends upon a device which has not yet entered into commercial switching systems. This is the subscriber preset keyset which, in effect, is a transmitting register located on the subscriber's premises. In one of its forms the device transmits signals repetitively and at an extremely high speed after the subscriber has keyed up the complete called number. This permits the passing of signals from the subscriber line directly into the marker as shown on Figure 6-5C without the necessity of an intervening central office register. On connections established to other offices, the same repeating signals from the subscriber keyset can again be used to inform a distant marker of the called line number. Thus the necessity of central office information transmitting means is eliminated.

6.5 SUPERVISION AND ALERTING

The supervising and alerting functions can in general be inserted at any convenient location in the concentrated part of the interconnecting network. There are, however, certain factors applicable to particular system plans that affect the location. It is desirable, for example, to combine into one unit all circuit elements such as relays that must be associated with each transmission path through

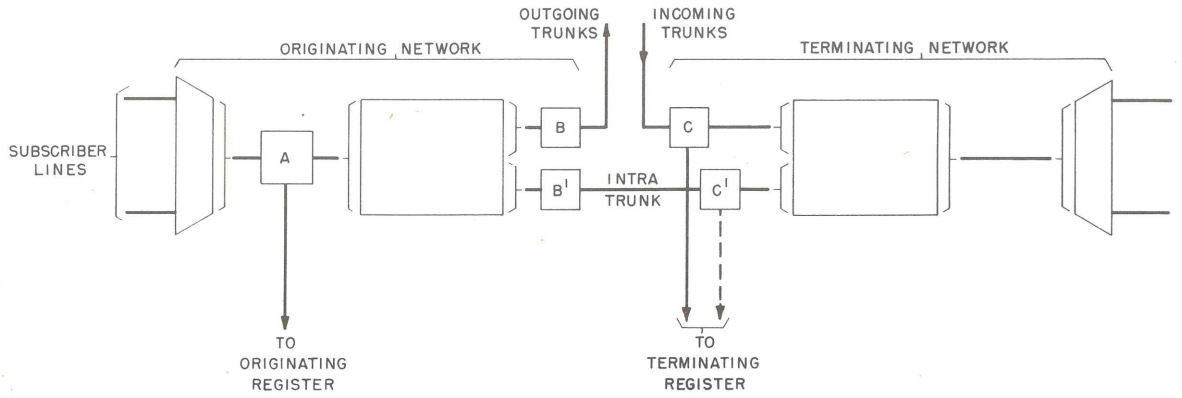


Figure 6-6 Location of Supervising and Alerting Function in Marker Systems

the network. A system plan that provides for connecting the originating register to the network as shown on the left side of Figure 6-6 may require circuit equipment at the location marked A. In this case supervisory equipment can also conveniently be located at the same place. Usually access is necessary from the marker to the supervisory and associated circuit and, at point A, this is possible either directly or through the register. Location A suffers from the disadvantage that a connection from A can in general proceed to any output trunk—intraoffice, outgoing, or special. Therefore any supervisory equipment at A must be of an universal type. Since the signaling conditions for interoffice supervision differ from those applicable to subscriber supervision, this universality is difficult to achieve unless additional supervisory equipment is placed at the terminating end of intraoffice trunks at the point marked C' on Figure 6-6. If this is done, the supervisory circuit at A faces similar conditions on all calls whether to the same or another office. Supervisory equipment at C' can be associated with the alerting function for ringing the called subscriber and with circuits necessary to provide access to a terminating register. Incoming trunks from other offices will of course require similar equipment at the location marked C.

A somewhat more efficient location for the supervisory circuits is at B or B' on Figure 6-6, rather than at point A. This is directly associated with the trunk and permits a single supervisory circuit for intraoffice calls instead of the two circuits required by the first plan. Intraoffice circuits at B' can include the subscriber alerting function; circuits at B can be designed to comply with the particular supervisory requirements of any connecting office.

6.6 TYPICAL SYSTEM LAYOUTS

The use of common control in a telephone switching system offers greater possibility of variation in the layout of the system plan than is possible in progressive type systems. In the latter, the interconnecting network was more or less fixed in form and this dictated to a considerable extent the location within the system of the affiliated switching functions.

A straightforward central office layout in which the office is divided into completely separate originating and terminating halves is shown on Figure 6-7A. This follows closely the principles that have been developed in this chapter. Registers are provided at both originating and terminating ends for reception of information, and independent markers establish connections through each part of the network. An originating call is first set up to a register by the connector control over a path through the concentration stage and a register connector. The first part of this path is held during conversation while the part through the connector is dropped when the register has completed its functions. After the register has received the office code from the subscriber, it connects to the originating marker which translates the code, locates a trunk, and establishes a path between the trunk and the previously connected output of the concentration stage. Incorporated in the register is information transmission means which transmits line number and in some cases office code to the terminating or intermediate office in whatever form is specified by the marker translator.

When a call arrives at the terminating office, whether originating in the same or another office, the incoming trunk is connected to a terminating register which records the line number. The register then connects to a terminating marker which determines line location from a separate line number translator or number group, tests the line for busy condition, and, if idle, establishes a connection from incoming trunk to line.

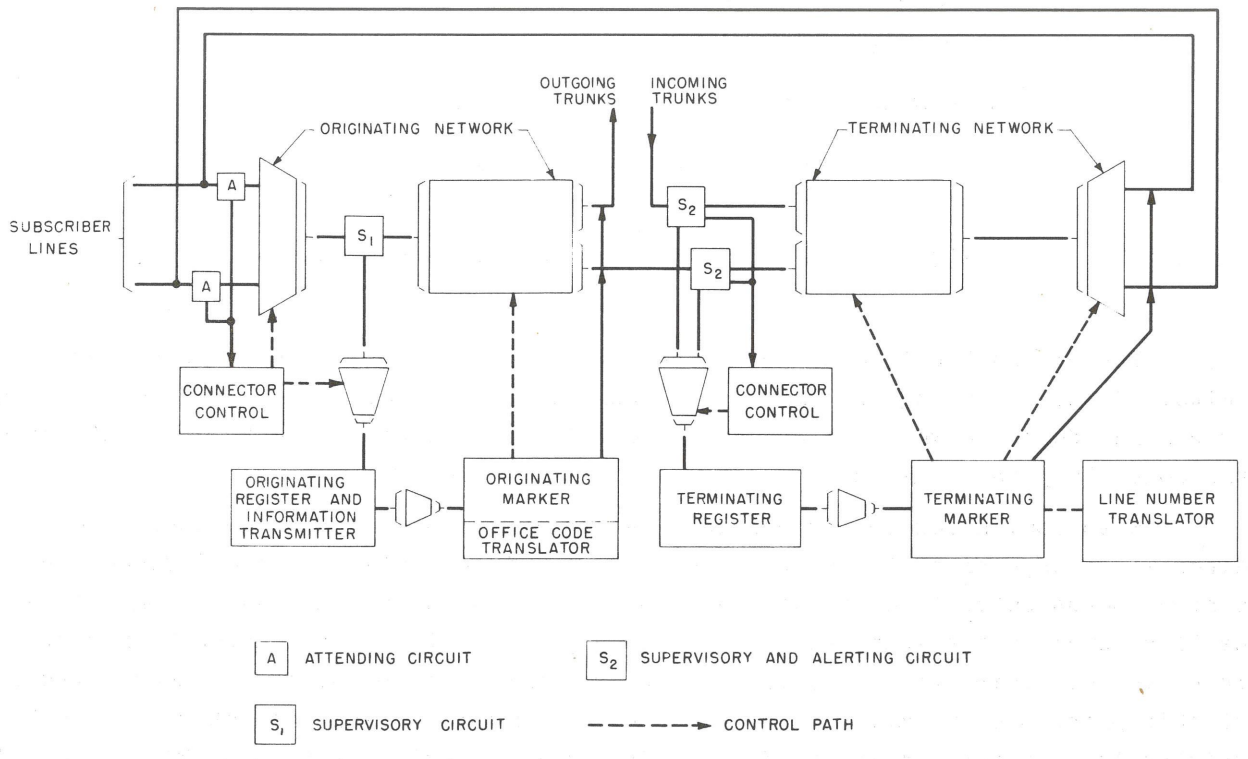


Figure 6-7A Typical Marker System Arrangements

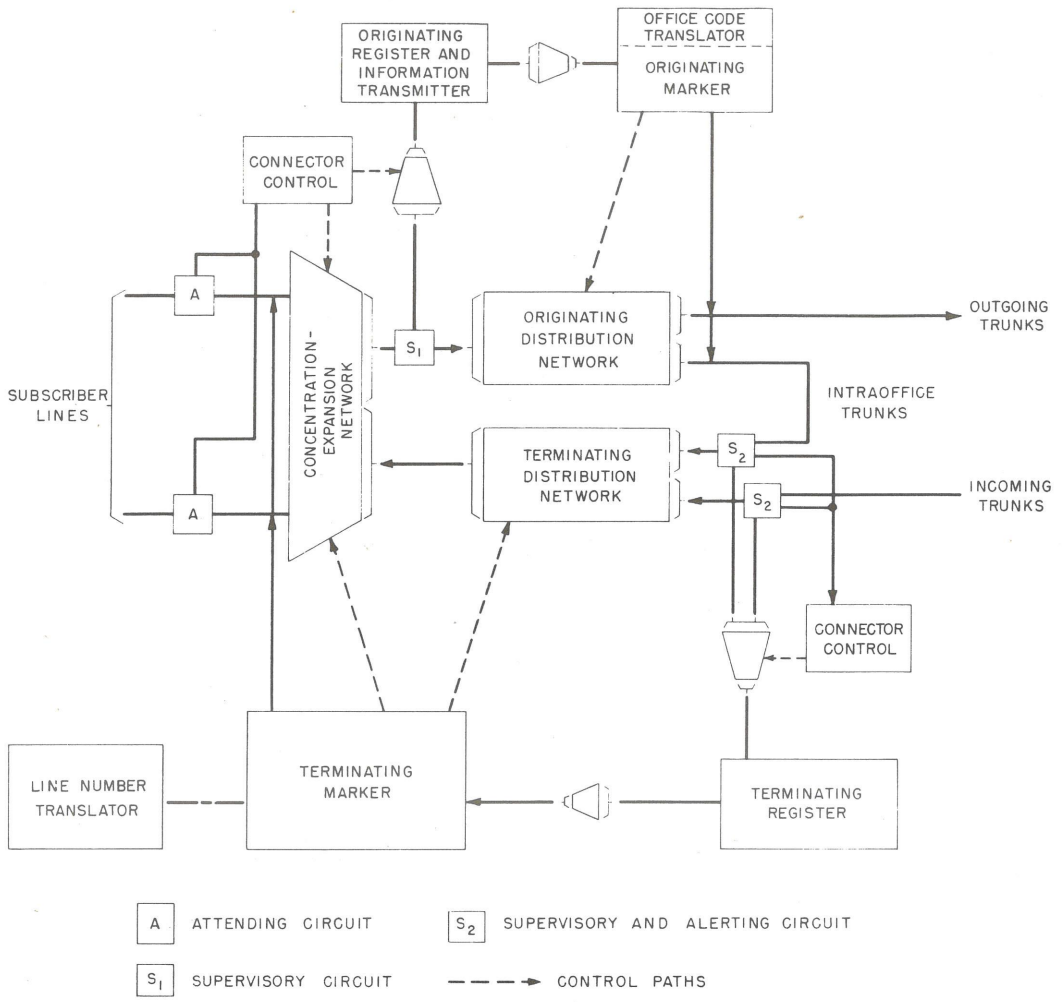


Figure 6-7B Typical Marker System Arrangements

The blocks labelled S1 and S2 on Figure 6-7A represent the supervisory circuits. The terminating supervisory blocks, S2, also include the subscriber alerting or ringing function which is set into operation by the common control circuit after the complete path is set up.

When common control principles are applied to a switching network, the directional aspects of the network tend to fade into insignificance. Since the control means establishes a path between two points rather than advancing a connection toward a termination, it is clearly possible to use the network in part or in whole for bidirectional traffic. The system plan of Figure 6-7B takes advantage of this principle by employing a combined concentration-expansion stage for both originating and terminating traffic.* In other respects the plan of Figure 6-7B is

*This system plan corresponds to the No. 1 Crossbar System.

identical to that of Figure 6-7A. The advantages of this scheme include a more efficient use of the switching network and elimination of the otherwise necessary multiple of subscriber lines between concentration and expansion stages.

The plan of Figure 6-7B requires that two independent and unlike common control circuits must have access to the concentration-expansion stage. One of these, the connector control unit, handles originating calls and sets up connections from calling lines through the concentration stage to supervisory circuits and thence through a connector to registers. The other, the terminating marker, completes connections to called lines through the same switch network. In general, the two control circuits cannot work into the same switch group simultaneously so that lock-out and preference circuits must be provided.

A third system plan that carries still further the bidirectional use of the network is shown on Figure 6-7C. Here not only the concentration and expansion stages, but also the originating and terminating distribution networks are combined.

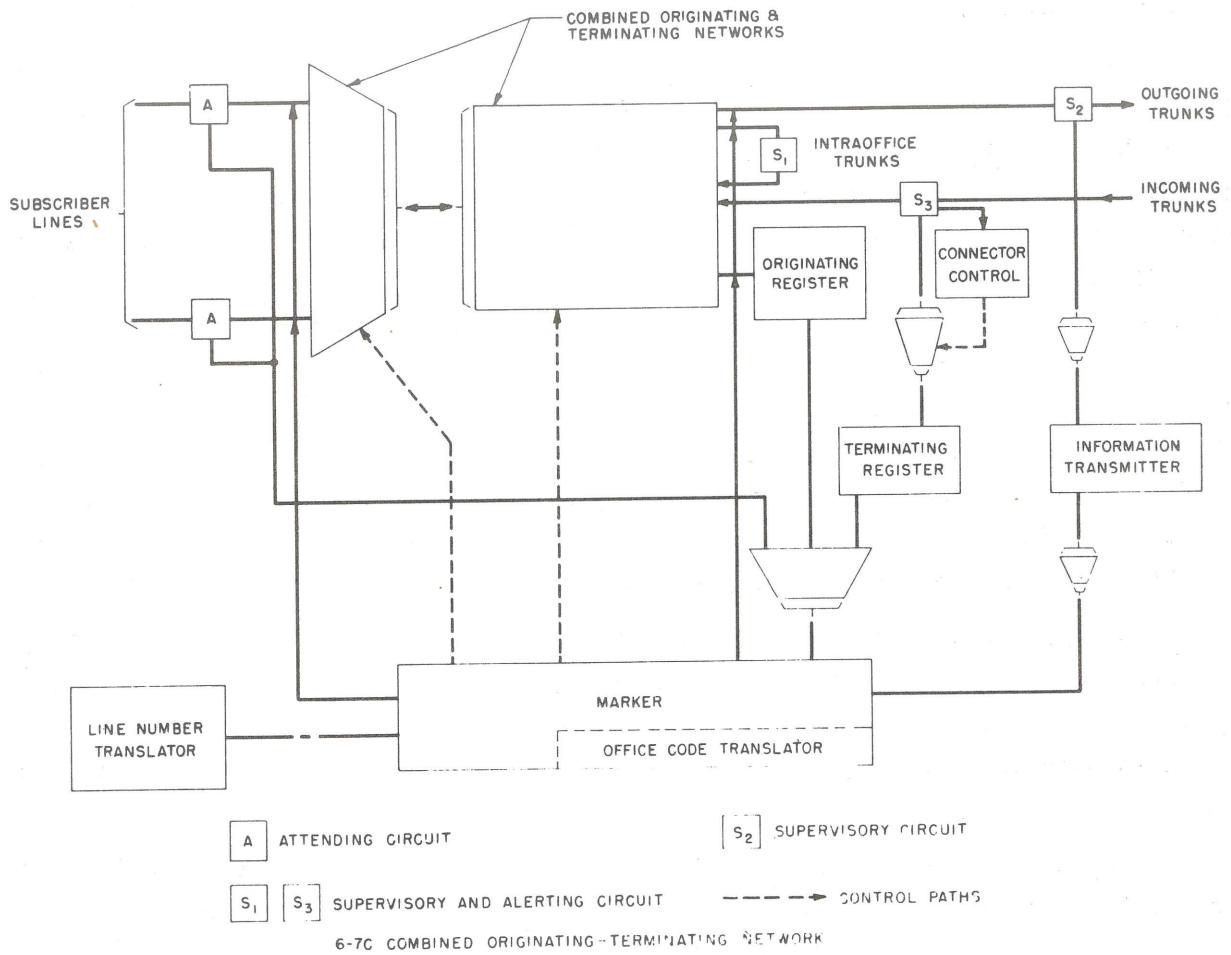


Figure 6-7C Typical Marker System Arrangements

Furthermore, the plan provides for use of the interconnecting network for originating register connection.*

This universal use of one interconnecting network makes possible a single type of marker which can establish all connections through the network. On an originating call, access is established from the line to the marker and the latter receives automatic notification that a connection to a register is desired. After the marker's office code translator determines the register location, the marker chooses an idle register and sets up a connection between it and the line. When the subscriber has completed dialing, the register gains access to the marker and passes to it the called number and the location of the calling line. This latter, recorded in the register by the marker on its initial usage, is necessary for completion of the connection.

If the call is to a line within the same central office, the marker chooses an idle intraoffice trunk, determines the called line location from the line number translator, and sets up connections from the intraoffice trunk to both calling and called lines. A single supervisory circuit labelled S_1 on Figure 6-7C, also includes an alerting circuit for ringing, suffices for the whole connection.

If the call is to another office, the marker determines the outgoing trunk group, chooses a particular trunk, and establishes a path between line and trunk. Since the connections from line to trunk and line to register are completely independent, there is no possibility of incorporating information transmission means within the register. Furthermore, it would be inefficient to provide information transmission means in quantity equal to originating registers since the former is not necessary on intraoffice calls. Therefore separate information transmission circuits of the appropriate signaling type must be associated with trunks on all outgoing calls. In Figure 6-7C this association is performed by the marker after the trunk is selected. The marker also transfers to the information transmission circuit over a separate access path the called line number to be transmitted. After marker, register, and the information transmission circuit have completed their functions and dropped off, the supervisory function is taken over by block S2.

On calls from other offices, the incoming trunk connects to a terminating register which receives and records the called line number. Again, the same type of marker is utilized to set up the connection from trunk to line. Block S3 includes both the alerting function for subscriber ringing and means for supervisory control.

Because of the use of a single type of common control circuit for all interconnection control, care must be exercised to insure equitable allocation of

*This system plan corresponds to the No. 5 Crossbar System.

markers to the three requesting sources: subscriber lines, originating registers, and terminating registers. For example, if lines requiring registers were permitted to monopolize the use of markers, the point might be reached where all registers were busy and could not get rid of their calls because originating lines were continuing to tie up the markers in attempts to connect to the busy registers. For this reason the marker connector circuit assumes a very important position in the system of Figure 6-7C.

One of the major complications in the system plans discussed thus far arises from the fact that several markers are necessary and that all of them must have access to the interconnecting network. This requires elaborate and expensive connecting circuits, including lock-out and safety features to prevent interference between control circuits. In addition, the efficiency of the markers is reduced by delays caused by competition. To a great extent these difficulties could be eliminated if control circuit operating time were low enough to require but a single marker for an office. However, with present design techniques this is not practical since a trouble condition could block all calls within the office.

A compromise plan which is just beginning to be explored involves distributing many of the control functions over the switching frames themselves rather than concentrating them. These distributed control functions for the most part have to do with the establishing of paths through the network when the terminal points are marked. For example, the system plan might provide for the register to determine the location of a trunk or line by means of a translator and mark with a voltage condition the calling and called terminals. The distributed control functions, probably electronic in nature, would then cooperate to set up a path between these two terminals. A system of this type depends upon extremely high acting speed of the control elements since only one call can be handled in the office at a time. It also requires a simple and economical control technique because control circuit elements must be duplicated on all switching frames of the network.

6.7 COMMON CONTROL PER SWITCHING GRID

Although the use of an individual common control unit for each switching grid in a multistage network has only been touched on in this chapter, there are certain special situations which warrant the use of this technique. For example, in the system plan of Figure 6-7A and 6-7B, this is the method of setting up calls through the concentration stage and through the register connector to registers. Figure 6-8 represents in a simple manner the switching plan utilized in this situation. Subscriber lines are grouped on switching grids which concentrate to a much smaller group of links connecting to the distribution stages. The output links are multipled to two or more of the concentration grids to provide the correct degree of concentration. The links also multiple to register connector grids which give

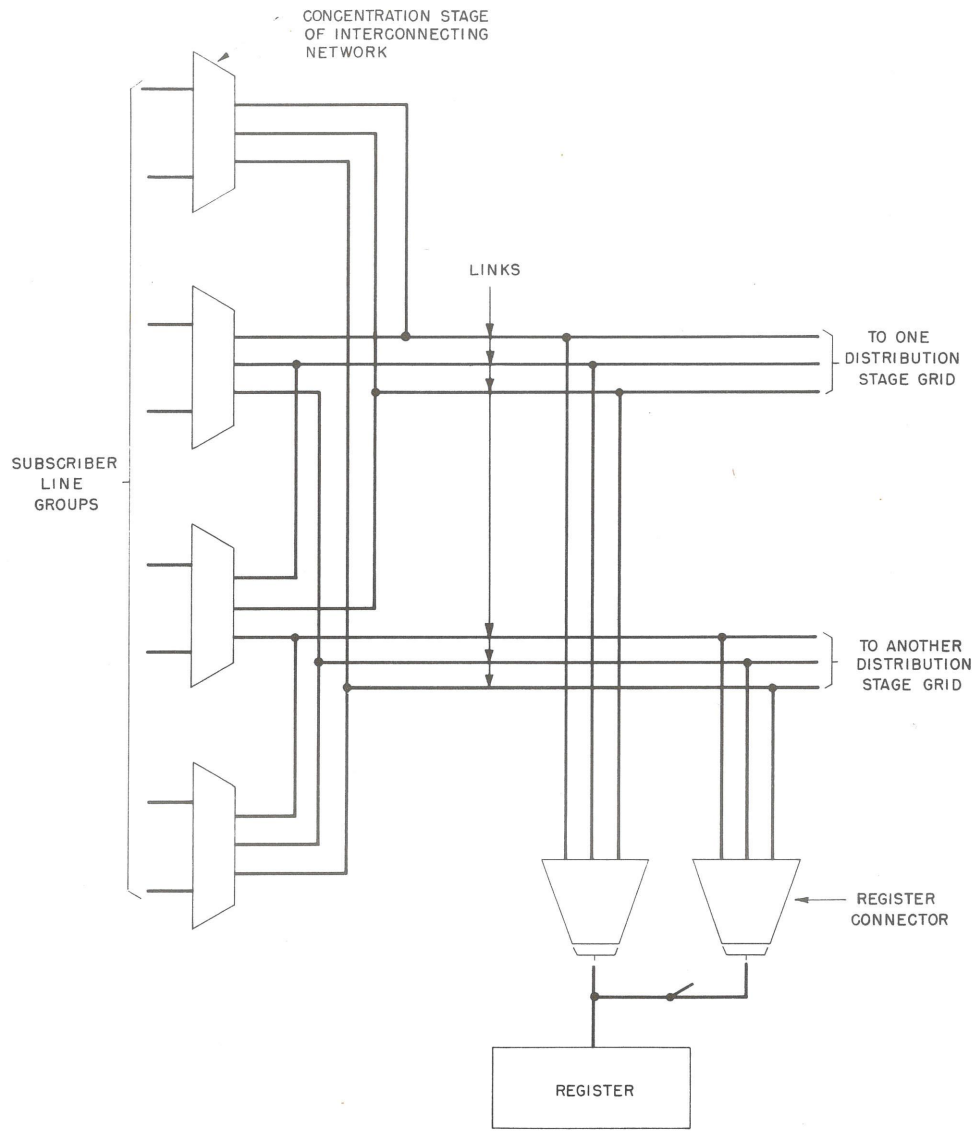


Figure 6-8 Switching Plan for Connecting Register to Subscriber's Line

access to the registers. Individual common control circuits are associated with each grid. This plan permits the simultaneous handling of several originating calls as long as the lines are located on different concentration grids. Simultaneous calls on the same grid of course must be handled in some planned order. This is one of the factors controlling the number of lines that can be placed on the same grid.

In order to set up a connection from line to register, it is necessary to know in advance that a selected link has access to idle paths to an idle register. Otherwise there is too great a chance of mismatch and consequent delay. This implies some degree of cooperation between the concentration stage control circuit and the register connector control circuit and rules out independence of control action. The most satisfactory way of achieving coordination is to provide paths

between the control circuits of the two stages by means of which any two can function as one combined circuit. Over permanently connected leads which comprise a part of these paths, information on the availability and general location of the idle paths and registers and the status of the control circuits can be interchanged. These paths are indicated by the heavy lines of Figure 6-9. When a call originates, a concentration grid control circuit thereby recognizes immediately with which register connector control circuit it can best serve the call. Temporary interconnecting paths between the two are then established which enable the two control circuits to act as one master circuit serving the two grids. This technique not only makes most efficient use of the switching paths and registers, but also conserves time.

It has been pointed out before that when a switching grid is served by an individual common control circuit, provision must be made for emergency operation in case of trouble. Two methods of taking care of this are shown on Figure 6-9. The concentration grids are grouped in pairs with emergency connections between the

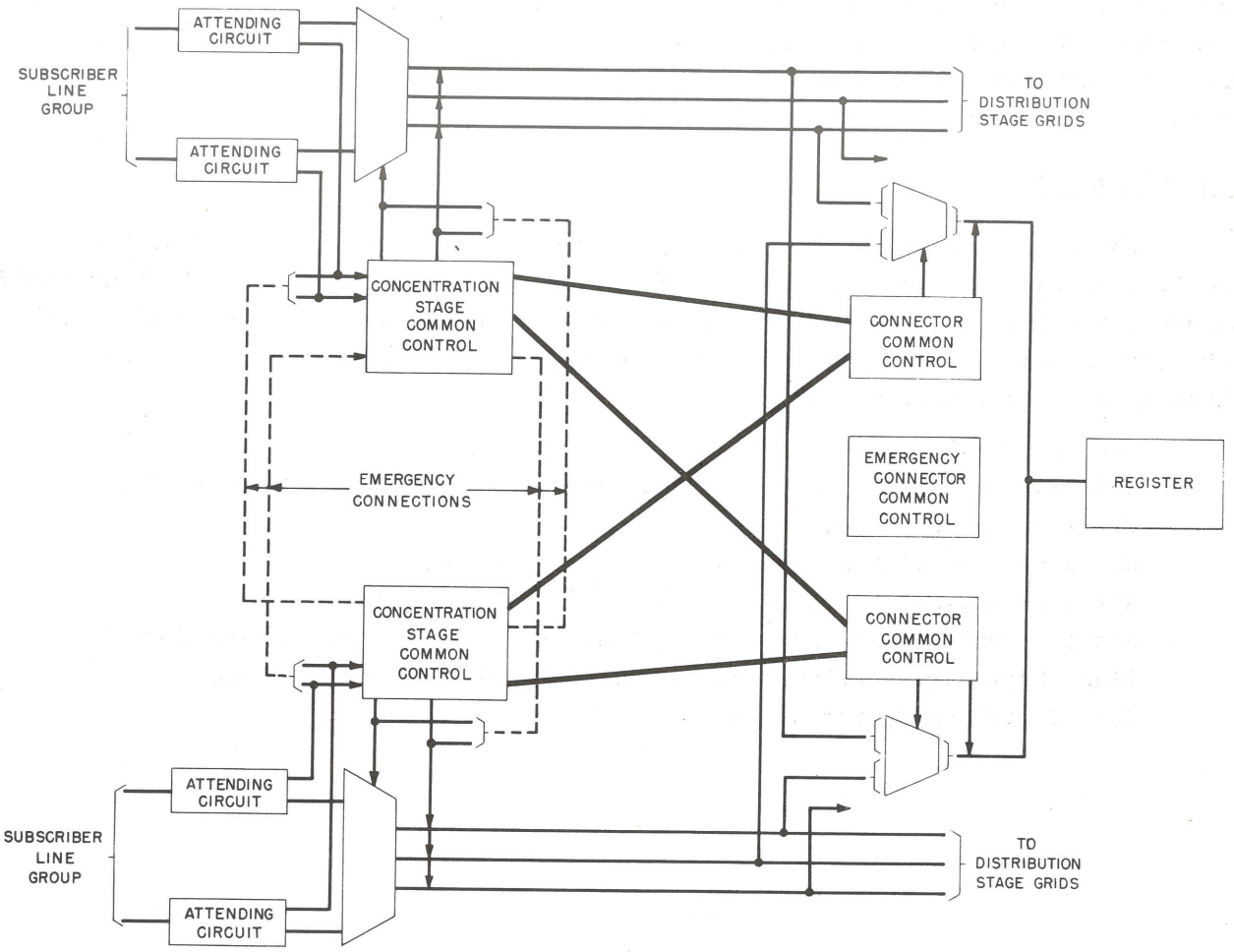


Figure 6-9 Common Control of Two-Stage Network With Control Unit per Stage

control circuits of each pair. If a trouble occurs in one circuit, the other can immediately take over the combined load of the two grids with little effect on service beyond a slight reduction in speed.

The condition is not so critical in the case of the register connector control circuits. Since each concentration grid can associate itself with any one of several connector grids, a temporary removal from service of one of the latter is not too serious. However, a small number of emergency control units are provided which can be substituted either manually or automatically for a regular unit in case of trouble.

6.8 CONCLUSIONS

The introduction of common control principles has greatly increased the scope and flexibility of telephone switching systems. In addition to all the advantages of register control, the interconnecting network is freed from the limitations of progressive control and more efficient arrangements become possible. The centralization of control functions into marker units permits the introduction of many new features to improve service which might not otherwise be economical. Common control provides a framework within which new techniques of path control and signaling make possible much higher switching speeds. The present Bell System plans for nationwide, automatically controlled switching are feasible only because of the capabilities of common control techniques.

6.9 REFERENCES

The best current examples of common control or marker switching systems are provided by the various crossbar systems in both the local and toll switching field. Number 1 and Number 5 Crossbar are local systems and Number 4, A4A, and 4A Crossbar (the latter under current development) are toll. Published material on some of these systems is listed below.

Crossbar Dial System (No. 1)—Out-of-Hours Test 164
Crossbar Dial Telephone Switching System (No. 1)—BSTJ, January 1939
Crossbar System No. 5—X-63878
Notes on Operating Features of No. 5 Crossbar—X-75202
Notes on Equipment Features of No. 5 Crossbar—X-75214
Notes on Maintenance and Testing Features of No. 5 Crossbar—X-75215
Plant Engineering Letter—No. 4 Toll Switching System—PEL-3334
Toll Switching System No. A4A—X-63885

CHAPTER 7

SIGNALING METHODS AND PROBLEMS

7.1 GENERAL

To establish telephone connections, subscribers must pass information to central offices and central offices must communicate with each other. When the switching systems are of an automatic type, the method of communication must be adapted to the characteristics of the component apparatus. This is done by means of signals which are produced by apparatus at one point and transmitted electrically to another point to cause other apparatus to respond. Signaling in automatic switching may be compared to communication between individuals by means of language. Spoken language consists of a sequence of sounds produced by vocal cords, transmitted through the air, and received by the ear. This however is merely the "mechanics" of speech. Information is not passed unless a series of sounds, such as a spoken word, has been assigned a meaning. The meanings of signals in switching systems are often determined by the particular functions to be performed or apparatus to be controled, while in other cases sets of signals are assigned in a formal code to represent items of information.

This analogy between signaling and language may be taken still further. A language may be represented in a written or spoken form, or by a braile alphabet, or in other ways, each adapted for different purposes and for different methods of recognition. Similarily in switching systems a number of different signaling techniques may be used according to the requirements of particular conditions. Also there are different languages such as English, or French, and likewise in signaling different codes may be used to represent the same information. It sometimes happens that two switching systems which "speak" a different "language" must work together. In these cases circuit units need be provided which act as "interpreters" to translate from one language to another.

Signaling in switching systems may be broadly defined as the act of effecting control or passing information from one point to another. The points may be located at a considerable distance from each other or they may be near by, as when signals pass between two units in the same office. From the discussions in previous chapters it is evident that signaling plays an important part in the proper functioning of any switching system. For purposes of discussion, signaling arrangements can be readily isolated from the switching systems in which they are used. This chapter presents primarily the basic signaling principles and techniques used between central offices, between subscribers and central offices, and between operators and central offices.

It was mentioned in an earlier chapter that although the primary purpose of a telephone switching system is to interconnect transmission channels, the characteristics of the channel are seldom of consequence in the development of switching systems. Signaling is perhaps the most important exception to this statement. Leads or paths primarily provided as a talking circuit or directly associated with such a circuit are widely used for the transmission of signals. Great care must be exercised in planning signaling applications and working out techniques so that there is no mutual interference between the transmission of voice and signals over the same channel.

The subject of signaling may be subdivided into a number of overlapping categories according to its purposes, basic principles, or circuit techniques. One of the broadest classifications is according to the switching function performed. This classification divides all signaling into the two general classes of supervisory and control signaling. Supervisory signaling is the means by which a subscriber or operator initiates a request for service, holds or releases a connection after it is established, or recalls an operator (in manual systems) on an established connection. Control signaling is the means for passing information which directs the establishment of a particular desired connection. It includes actions commonly thought of as "remote control." In some applications control signals simply pass information such as the called subscriber's directory number to a circuit which is able to take subsequently the proper action. In other cases the control signals directly actuate the switching mechanisms.

A second broad classification of signaling is according to the source of signaling power. This classification divides signaling techniques used both for control and supervision into direct-current and alternating-current signaling. direct-current (dc) signaling usually employs an arrangement of sensitive, polar, or marginal relays which respond to the strength or polarity of a dc current in an interconnecting circuit path. Alternating-current (ac) signaling usually employs frequency-sensitive receiving devices which respond to particular ac signals placed on a communication channel. The frequencies range from about 15 cycles per second up to about 2000 cycles per second and a variety of techniques are used, depending on particular conditions and requirements.

In the following paragraphs these broad categories of signaling are more fully developed and additional classifications are also introduced.

7.2 SIGNALING TECHNIQUES

Signaling between units within a central office is often over leads provided specifically for this purpose. However, the transmission of signals between a subscriber and a central office or between two central offices usually takes place over facilities primarily provided for voice transmission in a completed telephone connection. These facilities cannot be used for signaling without restrictions, and signaling methods must be arranged not to interfere with telephone conversations. In some cases this can be done by coordinating the signaling with the telephone traffic so that it is not necessary to transmit signals during times that

the circuit is used for conversation. However, since this cannot always be done in a practical manner, many signaling techniques have been developed which permit mutual use of the path for voice transmission and signaling. A fundamental signaling scheme must, of course, be simple, inexpensive, and reliable. For this reason, in many cases only a very limited number of distinctive signals are used. It is then often necessary to use combinations or sequences of signals to transmit adequate information or exercise proper control. The following paragraphs describe briefly some of the more important techniques used for signaling.

Dc Techniques—Short Range

The pair of conductors provided for a voice transmission channel in subscriber lines and local trunks are in almost all cases used for signaling. In the subscriber line, in links within a switching office, and in local trunks between switching offices, these leads are referred to as a loop. The two conductors are designated as tip and ring conductors corresponding to the parts of the plugs to which they are connected in manual switchboards. The same designations are retained in automatic systems.

Dc signaling over a loop is accomplished by causing changes in a current flowing through the loop. The current may be interrupted, its value changed between high and low levels, or its direction reversed. These changes are detected by suitable apparatus at the distant end of the loop. In practically all instances this apparatus consists of relays of sensitive, marginal, or polar types. Typical dc relay arrangements employed in loop signaling are illustrated in Figures 7-1, 7-2, and 7-3. Figure 7-1 shows a simple loop circuit where closure of a connection between the tip and ring conductors at one end of the loop causes a relay at the other end to operate. In Figure 7-2 a polar relay operates in response to reversals of battery and ground at the distant end of the loop. Figure 7-3 shows a method of transmitting and detecting four types of signals consisting of light and heavy positive and negative currents in the loop. The contact arrangement on the

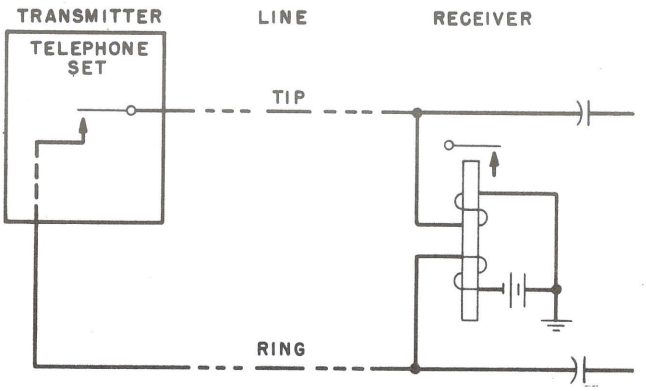


Figure 7-1 Simple D-c Loop Signaling Circuit

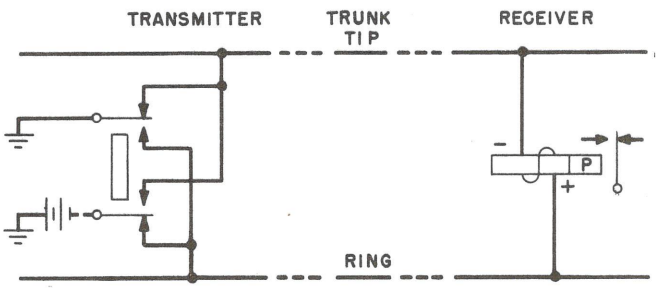


Figure 7-2 Reverse Battery Signaling

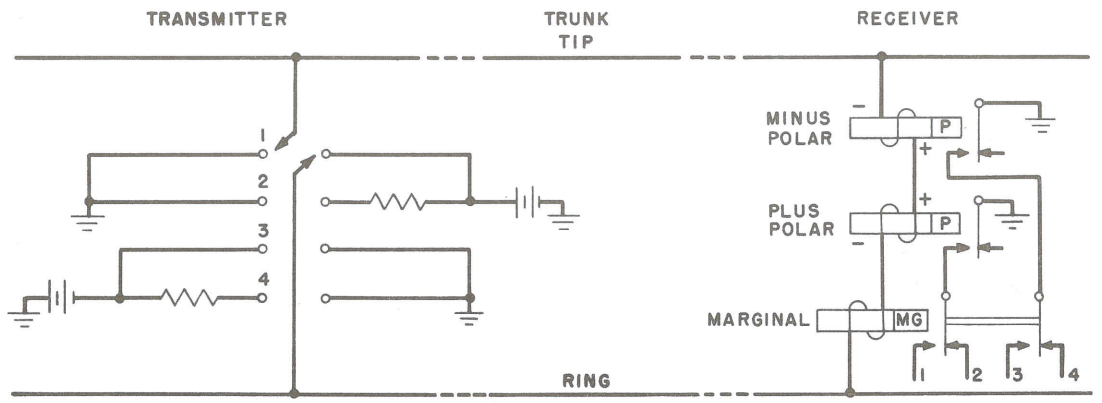


Figure 7-3 Marginal and Polar Signaling

polar and marginal relays illustrates how each of these distinctive signals can be caused to ground a particular one of four points. Due to adjustment limitations and battery supply variations, signals which require distinguishing between many values of current are not practical. Practical dc signaling arrangements using the loop conductors must meet a wide range of variations of loop length and leakage resistance to ground and between conductors. This limits the possible applications of simple dc arrangements. In longer circuits where more elaborate detecting devices would be required, other methods, described later, are more reliable. Signaling between a subscriber and a central office is almost always on a loop basis employing simple open and closed loop conditions.

In order to produce additional signals, the loop conductors are sometimes used with a ground return. The conductors may be used individually or together. Such arrangements are grounded arrangements, while those employing conductors for the complete loop are metallic arrangements. Grounded arrangements must contend with wider variations than metallic, chiefly due to earth potential differences between the two ground points at the ends of the circuit.

Dc Techniques—Long Range

When the length of the transmission loop is increased, dc signaling techniques for switching are adapted from circuit arrangements used for telegraph transmission over telephone facilities. They employ sensitive polar-type relays and often make use of a ground return circuit to complete the dc path. One of the problems is to obtain metallic dc paths derived from the line conductors in a way that does not interfere with voice transmission. One means of accomplishing this is to signal by means of a simplex arrangement, as shown in Figure 7-4, which employs center taps at each end of the line so that the signaling currents through the simplex path balance on each line conductor and thus produce no voltage across the line which is the transmission path.

Simplex arrangements are generally used on circuit paths within the telephone office when loop methods do not provide a sufficient variety of signals for

all needs. Simplex arrangements are seldom available for signaling on longer trunk circuits since two simplex paths are often combined to produce a transmission circuit called a phantom which, together with the two side circuits as shown in Figure 7-5, permits three simultaneous telephone conversation channels on two loops. When this is done there is a problem of obtaining signaling channels over two pairs of conductors for three voice transmission channels.

Another type of dc path used for signaling purposes is the composite circuit, or CX circuit, shown in Figure 7-6. This is essentially a high and low-pass filter arrangement which separates the dc and low-frequency signaling currents from those of the voice, the separation point being around 100 cps. Part of the high-pass characteristic of the arrangement is obtained by the use of repeating coils which greatly attenuate low frequencies. When the trunk conductors of a phantom group, such as in Figure 7-5, are equipped with composite sets, four signaling paths are obtained which can be used independently with a ground return.

The relay circuit arrangements provided at the terminals of a CX circuit for signaling are adapted from the differential polar duplex systems used in telegraph and teletypewriter transmission. These employ a sensitive multi-winding polar relay at each end of the circuit. They make use of ground return and require balancing networks which much be adjusted for each circuit according to the impedance of the trunk conductors. Signals may be

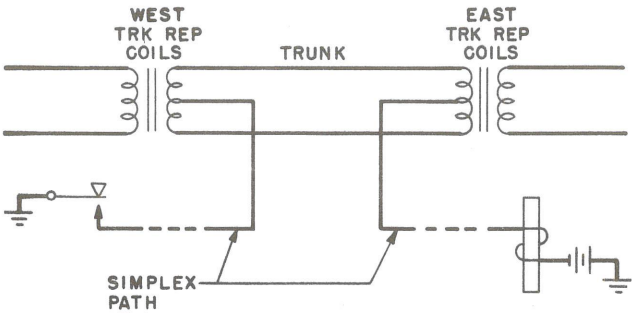


Figure 7-4 Simplex Circuit

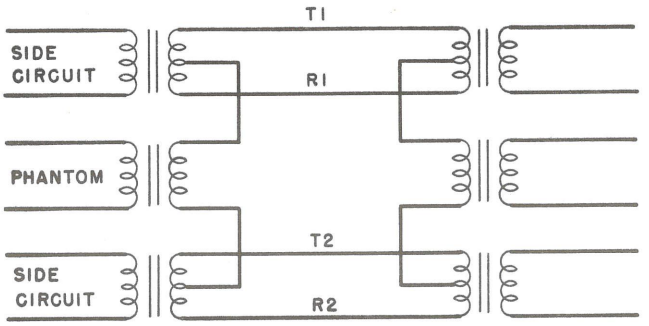


Figure 7-5 Phantom Circuit on Two Pairs

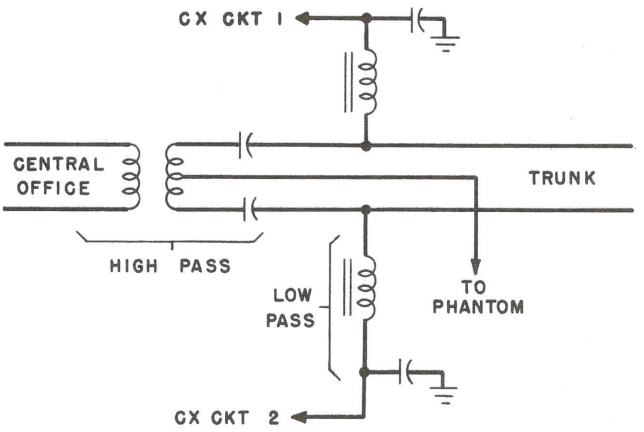


Figure 7-6 CX Circuit for One End of A Trunk Pair

independently transmitted in both directions simultaneously by the use of these arrangements.

Earth potential differences which would reduce the range and reliability of CX circuits are compensated for to a great extent. An additional CX path connected through compensating windings on the polar relays at each end so as to counteract the earth currents in the operating windings is used. When phantom arrangements are used, three of the CX leads are equipped for signaling, and the fourth CX lead is used for earth potential compensation of the signaling relays in all three circuits. This arrangement is widely used for the purpose of controlling automatic switching equipment.

Ac Signaling Techniques—General

Ac signaling is widely used over longer circuits such as intertoll trunks where simple dc methods are not practical. The signal currents use the transmission channel in the same manner as the voice currents.

Ac signaling techniques may be divided according to frequencies employed into three categories: low, intermediate, and voice frequency systems. Distinct frequency bands occur because of the characteristics of facilities provided for telegraph and voice transmission over communication channels. Low frequency ac signaling uses the band of frequencies below 100 cycles. These frequencies cannot be used where CX signaling is used, or where the CX channels of an intertoll trunk are used for the transmission of telegraph or teletype signals. Intermediate frequency ac signaling is in the band between 100 cycles and 250 cycles and is thus above telegraph frequencies and below voice frequencies. Neither low nor intermediate frequency signals will pass satisfactorily through the amplifiers or "repeaters" provided for voice frequencies on transmission channels, and such signals must therefore be relayed around these repeaters. Voice frequency signaling employs frequencies in the voice band. These signals are amplified by voice repeaters and may be transmitted directly over any communication channel that transmits voice.

Ac Signaling Techniques—Low Frequency

Low frequency ac signaling was the first form of ac signaling employed in telephone operation and originated with the hand-cranked magneto of early systems. The magneto was used to ring the telephone bells of the subscriber, and was also used by the subscribers to signal the operator in the central office, and by an operator to signal another operator in a distant office.

In present-day local switching systems, dc loop signaling has generally replaced the magneto for signaling from subscriber to central office, but the telephone bells of subscribers are still operated directly on ac from a generator in the central office. The frequency which is nominally 20 cps may vary from 16-2/3 to 20 cps. On party lines a dc bias is sometimes superimposed on the ac in a selective ringing system to permit ringing only one of two parties on the same line. The bell mechanism is arranged by means of magnetic bias or a cold-cathode gas tube

to respond to a particular polarity of superimposed dc bias. The method is extended to four-party selective ringing by using a choice of one of the two line conductors and a ground return.

Twenty-cycle signaling is also used on trunks between offices for signaling between operators. Electro-mechanical ac relays in electrically tuned circuits respond to these signals and cause the operation of electro-mechanical dc relays which may light lamps in a switchboard or cause other actions. Figure 7-7 shows 20-cycle signaling equipment for ten trunks.

Low-frequency ac signaling is widely used because of its simplicity and economy but there are many restrictions to its use. The interference with CX channels has been mentioned. The limited sensitivity of receiving relays prevents its use on long circuits. Some problems also arise because the frequency is near that of dial pulsing.

Low-frequency signaling arrangements are relatively slow. The chief reason for this is that a signal of sufficient duration to be recognized as a signal must consist of several full cycles, which at 20 cps must last an appreciable fraction of a second. Also the relays responding to 20 cps are subject to momentary false operation due to transients on the transmission channel. Protection from such false operation is obtained by means of an auxiliary slow-acting relay which does not respond until a 20-cps signal has been present for a satisfactory period.

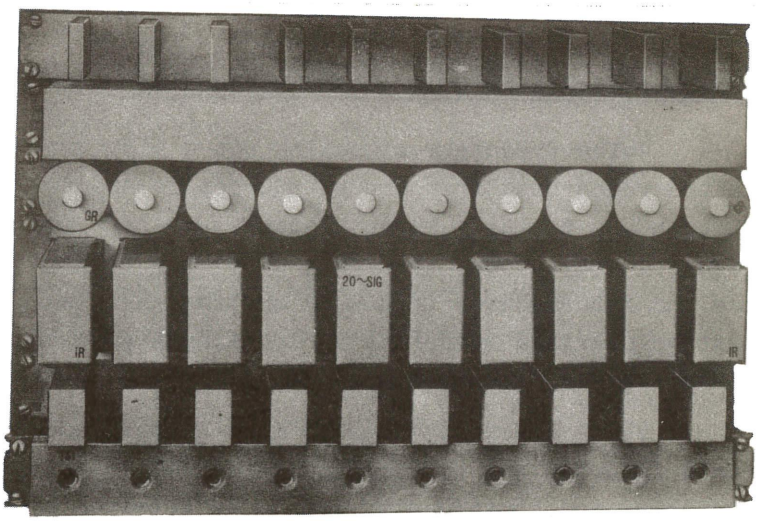


Figure 7-7 Unit of Ten Circuits for Receiving 20 cps Signals

Ac Signaling Techniques—Intermediate Frequencies

Intermediate frequency signaling was developed to allow signaling by relatively simple means on transmission channels in which the CX circuits are used for telegraph. A system employing 135 cps current is used to a limited extent on intertoll trunks. Signals are received by means of a tuned-reed relay which is connected in a tuned circuit arrangement across the conductors of the voice circuit. The relay is quite sensitive, operating on less than a quarter of a milliampere of 135-cycle current. This relay requires the use of auxiliary slow-acting relays for satisfactory operation and the speed of signaling is consequently slow.

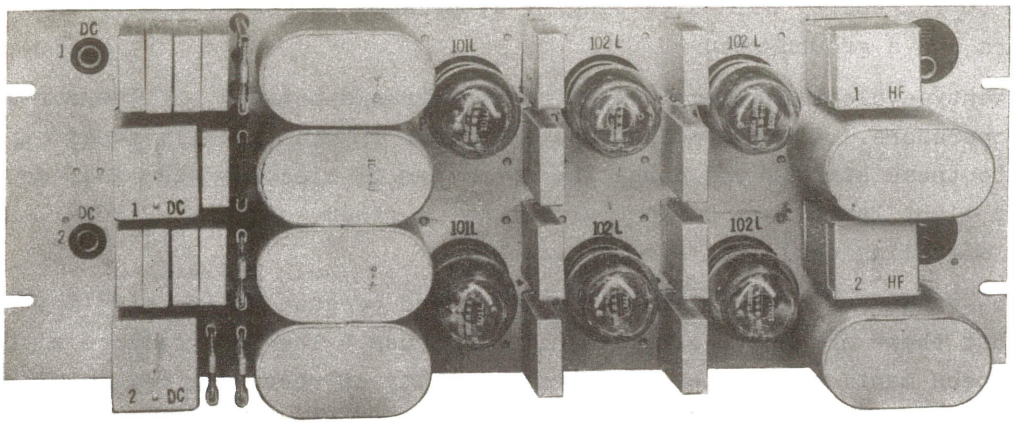


Figure 7-8 Apparatus for Receiving 1000/20 Cycle Signal—Two Units on One Panel

Ac Signaling Techniques—Voice Frequencies

Voice frequency signaling has a wide variety of applications. Frequencies in the voice band from around 500 cps to about 2000 cps are used and will pass through any facility which transmits voice. Therefore signaling equipment is required only at the terminals of a long transmission path. This is not true of low and intermediate frequency systems where at each voice repeater point equipment must be provided to detect an incoming signal and send out a new signal on the other side of the repeaters.

Voice frequency signals must be the same order of amplitude as voice currents in order not to overload voice amplifiers or cause cross-talk in adjacent channels, and consequently cannot be detected by present-day electro-mechanical devices. Vacuum tube detectors with electro-mechanical relays in their output circuits are widely used. An example is shown in Figure 7-8. These are generally more expensive than the electro-mechanical relays used for low and intermediate frequency signals, but their cost is offset in long circuits by the elimination of signaling equipment at intermediate repeater points.

One of the chief problems in voice frequency signaling is to prevent mutual interference between voice and signals. Voice frequency signals are audible and consequently signaling must not take place at times the channel is used for conversation. Signal receiving equipment however must remain on the channel during conversation to be ready to respond to an incoming signal and it may thus be subject to false operation from voice sounds which resemble the tones used for signaling. Protection against voice interference is accomplished in a number of ways.

One method is to choose signal tones of a character not likely to occur in normal speech. In so called "1000-cycle signaling" a frequency of 1000 cps is interrupted (or modulated) at a 20-cps rate. See Figure 7-9. Tuned circuits in the receiver respond only if the tone frequency and modulation rate is within

prescribed limits. In multi-frequency systems several frequencies are combined and individual receivers set to respond to each frequency. Usually two frequencies are transmitted simultaneously. In such multi-frequency signaling systems, self-checking codes, to be described later, give protection against false operation.

Time delay is often used to prevent false operation due to voice. The voice frequency signal receiving apparatus is made slow to respond so that normal noise or voice currents which would otherwise actuate the receiver are ignored. This is often accomplished by means of a slow-acting relay in the output of the receiver.

In some signaling systems a guard channel is used to protect against voice interference. This consists of a signal receiver arranged by means of filters to respond to a band of noise and voice frequencies other than those used for signaling. Operation of this signal receiver disables the normal signal receiver to prevent false actions. Ideally the filters of a guard channel should respond to all voice frequencies except those used for signaling. In practice the filter is usually a simple resonant circuit broadly tuned in the low frequency range of the voice band at around 500 or 600 cps and will cut off at the higher signal frequencies.

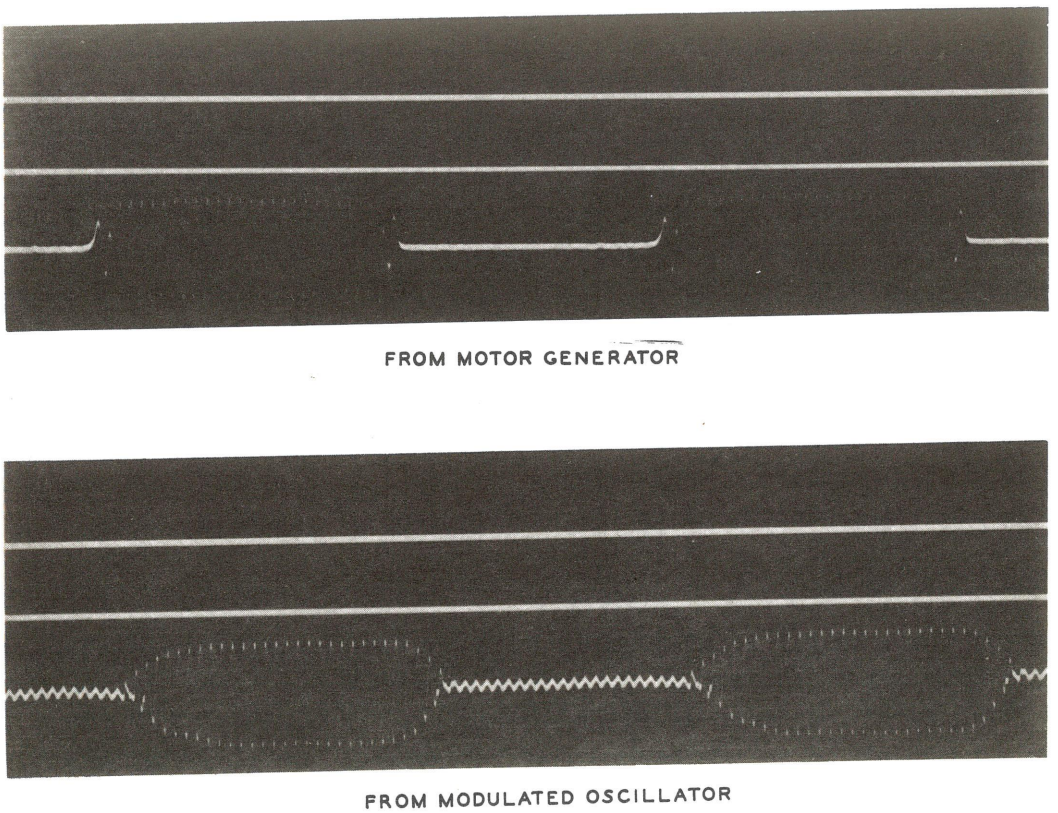


Figure 7-9 Oscillograms of 1000/20 cps Signaling Current
Top: From Motor Generator
Bottom: From Modulated Oscillator

Ringers

In manual switching the term "ringing" is often used synonymously with "signaling," since the operating procedure employed in ringing the bell of a subset is the same as that followed in signaling between offices. Between the originating and terminating switchboards it is often necessary to repeat the signals at intermediate points, and the circuit units which receive incoming signals and re-transmit a new signal are called ringers.

In low and intermediate frequency ac signaling, ringers are required at voice repeater points. These ringers consist of ac signal receiving relay circuits bridged across both inputs of a two-way repeater. The circuit is arranged so that a signal coming into one side of the repeater will cause a fresh ac signal from a local ac supply of the proper frequency to be sent out on the other side of the repeater. By passing a fresh signal from one ringer to another it is possible to signal over long circuits. However, since each ringer is inherently slow to respond, several seconds are required to transmit a through signal and the method is not suitable where short signal impulses are required.

In connecting together line sections to provide a transmission channel between two remote points, it may be necessary to use lines equipped with different types of signaling facilities. In these cases ringers are provided which receive and send different types of signals on each side. An example is the "20-135 cycle ringer" which, in one direction, receives 20 cps signals and sends out 135 cps and, in the other direction, receives 135 cps and sends out 20 cps. Ringers of this sort are made for all combinations of 20, 135, and 1000-cycle signaling.

Ringers are extensively used with manual toll switchboards because the cord circuits of a switchboard must work with any trunk connected to the switchboard and all trunks may not have the same type of signaling. In one switchboard (No. 1 toll) the cord circuits can send and receive only 20-cycle signals and consequently all trunks signaling at other than 20 cps must be converted by means of ringers. In another switchboard (No. 3 toll) the signals to and from the cord circuit are of dc type. Trunks for this switchboard are equipped with ringers which send and receive signals using ac of the appropriate frequency on the trunks, and dc on a lead connecting to the switchboard. These ringers are called 20 cycle-, 135 cycle-, or 1000 cycle-dc ringers according to the ac frequency of signaling.

7.3 LOCAL SUPERVISION

In practically all local switching systems, supervision is by means of a dc loop. The switchhook contacts of the subset close the loop when the receiver is lifted. Relays or other devices in series with the loop cause the central office equipment to respond to an initial request for service and supervise the holding of the connection as it progresses through the switching stages and while conversation is in progress.

The general rule in local switching systems is that a supervisory relay must remain operated in series with the loop for the control circuits to continue their

normal routines in setting up the connection. Also, after the connection is established, the switches are held operated as long as the supervising relay involved remains operated. Restoring the receiver of the subset to terminate a call at the end of a conversation, or to abandon it while it is in the process of being set up, will cause the supervisory relay to release and to restore all circuits and switches to normal. Auxiliary slow release relays are usually provided in supervision so that momentary open loop intervals, due to accidental action of the switchhook contacts or dial pulsing, will not cause the false release.

In manual systems, supervisory signals are given to the operator by means of lamps. The general philosophy is that a lighted lamp is a signal for some action on the part of the operator and performing this action causes the lamp to be extinguished. Lifting the receiver of the subset causes an answer lamp in the face of a switchboard to light, indicating to an operator that the associated line wishes to originate a call. Answering this request by plugging a cord in the line jack extinguishes this lamp and supervision is transferred to the cord circuit which contains a lamp which lights for the receiver "on-hook" condition. A flashing cord lamp caused by the subscriber operating and releasing the switchhook mechanism indicates to the operator that a subscriber desires attention while a steady cord lamp is a disconnect signal.

7.4 TOLL SUPERVISION

In toll circuits, CX or ac signaling is mostly used for supervision. Supervision on these circuits follows one of two procedures which are known as ringdown and straightforward supervision.

Ringdown Supervision

In ringdown operation an operator signals to a distant operator by operating a ringing key in a cord circuit which places a ringing signal on the trunk. This is a separate manual operation which may be performed at both the start and end of a call. The name "ringdown" is a hold-over from early switchboards which used "drops" instead of lamps as signals. Signaling between operators is then done by "ringing down" the drops. Ringdown signaling makes use of the various types of ringers previously discussed and consequently is quite slow, requiring about a two-second ring for the relays at a distant switchboard to respond.

Straightforward Supervision

Straightforward supervision requires no specific signaling actions on the part of an operator and is used in both local and toll manual systems. Inserting a cord in a trunk jack automatically causes the lighting of an answering lamp at the distant switchboard, and removing the cord gives the proper disconnect signal. Dc signals transmitted over a loop are used for supervision between local offices. CX signaling circuits are widely used for straightforward operation of toll circuits as is also the single-frequency ac system described later. This type of supervision greatly speeds up telephone service as compared to ringdown, since signaling is automatic and rapid.

7.5 CONTROL SIGNALING

Control signaling as distinguished from supervision is concerned with passing information which identifies the called line or trunk, or controls the operation of switches to make the desired connections. Control information is usually in the form of a number which may contain as many as eleven digits in the case of toll calls. Rapid signaling methods are required to transmit these multi-digit numbers in a reasonable time. In some systems only one variety of signal condition is possible (for example, the simple closure of a loop) and in these cases a series of signals must be transmitted in time sequence. In other systems described later, a variety of signal conditions are possible and can be sent in code combinations, simultaneously or in sequence, to represent the necessary information. In some systems the same signaling technique is used for both control and supervisory signaling.

Dial Pulsing

A widely used method of transmitting information is by means of dial pulses which consist of trains of current interruptions generated by a contact in the telephone dial mechanism or by a circuit equivalent. The value of each digit corresponds to the number of pulses in each train. The speed of dial pulses is usually about ten pulses per second. The individual digits of a number are separated by a relatively long time between digits.

In local switching systems the subscriber loop is used for dial pulsing as well as for supervision. Since the loop is closed at the time the receiver of the subset is lifted and must remain essentially closed for supervisory purposes, dial pulses must consist of momentary open intervals of the loop which are ignored by slow-release relays in the supervisory circuits. Dial pulsing on a loop basis is also frequently used on trunks between local offices. On short haul toll circuits CX signaling arrangements are often used to transmit dial pulse type signals.

Dial pulses are utilized by automatic switching systems in two ways. In direct control systems the pulses directly actuate the switch mechanisms, causing a ratchet to advance the switch brush, one step for each pulse, to a desired group of outputs. The switch mechanism by self-actuating means locates an idle output in the group and connects the loop leads through to a switch in the next stage during the interval between digits. In register and common control systems the dial pulses are counted by relay circuits and registered on relays or switches before any action is started toward establishing a connection.

Codes

Available signaling techniques employ only a small number of different types of signals so that a number of signals must be combined in order to represent the full information required to control switching. These signals may be sent in time sequence over a single channel or simultaneously over a number of channels. For example two components of a switching system may be interconnected by a number of

leads. The signal condition on each lead may consist of placing ground on the lead and the leads may be grounded in combinations. A code to represent any desired information is constructed by arbitrarily assigning combinations of conditions to represent particular bits of information. Information is often recorded by operating relays in combinations according to such an established code. Much of the information transmitted and recorded in telephone switching systems is expressed in the form of numerical quantities and codes representing digit values from 0 to 9 are extensively used.

Many switching circuit elements are basically "two-valued" devices; for example, a relay is either operated or released or a lead is either grounded or open. One of these two conditions is a normal or inactive condition while the other is an active condition, and a code can consist of combinations of these active conditions. To represent the ten decimal digits requires at least four two-valued elements such as relays or leads. A number of four-element codes are in use, most of these being additive codes. In an additive code the element is given a numerical designation and the value of the digit represented by a particular combination is equal to the sum of the designations of the elements activated in that combination. Several of these codes are given in the table of Figure 7-10. In certain switching systems registers are provided which count incoming pulses representing numbers and record each digit as it is received in one of the codes of Figure 7-10. After all necessary digits are received, they are transferred simultaneously to other control circuits over a number of interconnecting leads where the code consists of combinations of grounds (or battery) on the interconnecting leads.

Another type of code is the self-checking code, examples of which are shown in the table of Figure 7-11. These codes are distinguished by the fact that each combination contains the same number of active elements (two) and consequently can

Digit	1-2-4-5 Code	1-2-4-6 Code	1-2-4-8 Code
0	1-4-5	4-6	2-8
1	1	1	1
2	2	2	2
3	1-2	1-2	1-2
4	4	4	4
5	5	1-4	1-4
6	1-5	6	2-4
7	2-5	1-6	1-2-4
8	1-2-5	2-6	8
9	4-5	1-2-6	1-8

Figure 7-10 Four-Element Additive Codes

Digit	Additive 2-Out-Of-5 (0-1-2-4-7)	Bi-Quinary (A-B-0-1-2-3-4)
0	4-7	A-0
1	0-1	A-1
2	0-2	A-2
3	1-2	A-3
4	0-4	A-4
5	1-4	B-0
6	2-4	B-1
7	0-7	B-2
8	1-7	B-3
9	2-7	B-4

Figure 7-11 Self-Checking Codes

be checked for error by determining the number of active elements. At least two errors are necessary for one combination of the code to be falsely changed to another. For example in the self-checking codes shown in Figure 7-11 one relay must falsely operate and another falsely release. A single error will leave one or three relays operated and this can be recognized as a trouble condition.

The 2-out-of-5 code is replacing the older four-element codes in automatic switching systems because of its self-checking ability. It is also used in ac signaling systems where the elements of the code are represented by voice frequency tones transmitted in combinations of two at a time. The bi-quinary code is used in relay computers and in telephone switching control circuits.

Dc Key Pulsing

A method known as Dc Key Pulsing is used to permit operators located in the same building with automatic switching equipment to pass control information rapidly into switching control circuits. The transmitting equipment consists of a 10-button key set and each digit is transmitted by momentarily depressing the appropriate key. The signaling arrangement uses two leads and a ground return. Sensitive, polar, and marginal relays are used on each lead at the receiver and contacts on the keys of the key set apply battery or ground directly or through series resistors to the two leads in a coded arrangement which causes the receiving relays to operate in the equivalent of a 1-2-4-5 additive code. Each digit is recorded on a separate set of register relays. Due to the use of a ground return and marginal conditions for operating the code receiving relays, this system is used only by operators to control automatic switching equipment in the same building.

Multi-frequency Signaling

Multi-frequency (MF) signaling is an ac voice frequency method employing five tones transmitted two at a time in the 2-out-of-5 code of Figure 7-11. The frequencies used for digit transmission are 700, 900, 1100, 1300, and 1500 cps. An additional frequency of 1700 cps is used in some cases so that additional two-frequency combinations can be used for circuit control purposes. Signals are received by vacuum tube detectors which are arranged to operate register relays for each digit. A check circuit arrangement verifies that only two of the five (or six) relays operate for each digit. This system is used by operators in controling distant automatic switching equipment. The tone frequencies are supplied by common oscillators or generators and each operator uses a 10-button key set. In some switching systems multi-frequency signaling is used to pass information over trunks between control offices.

There is also a possibility of replacing the dial of the subscriber telephone set by a multi-frequency signaling key set. One version of the proposed subscriber key set uses five vibrating reeds as tone generators and these reeds are mechanically plucked in the proper combinations by depressing the keys of the key set.

Single Frequency Signaling

One of the voice frequency signaling systems employs a single frequency tone of 1600 cps for control and supervisory signaling on toll trunks. This system is known as single frequency or SF signaling. A feature of this system is that the signaling tone is placed on the channel to indicate and maintain an idle condition and is removed to make the channel busy.

The operation of this system is briefly as follows: In the idle condition a 1600-cps tone is transmitted from each end of the trunk to hold signal receivers at the opposite ends in a normally operated condition. When a connection is to be established and the circuit is seized at one end, the tone source is removed at that end. This signals the distant end to prepare for service, and when preparations are completed it responds by removing its tone, leaving the voice channel clear in both directions. Further control signals necessary to properly condition the terminating apparatus at both ends are transmitted by short 1600 cps tone signals. The system transmits dial pulses by converting them to tone pulses. At the conclusion of a call the reapplication of steady tone is a disconnect signal which restores the terminating apparatus to normal, and tone remains on in both directions until the circuit is used again.

Since the tone receivers are on the circuit during conversation, protection against voice operation is necessary. This is accomplished by means of a guard channel, and by reducing the sensitivity as well as introducing a time delay in the receiver. In some applications the SF signaling system is used only for supervision, and control information is transmitted by multi-frequency signals which are much more rapid than dial pulses.

Revertive Pulsing

Certain switching devices, notably panel selectors, are driven by their own power to pass over a bank of terminals and signal their position at each step by producing a pulse as each terminal is passed over. The pulses are generated by a commutator which is part of the switch mechanism. Equipment at the originating end of the trunk counts these pulses and stops the switch by means of a signal over the trunk when the desired position is reached. This method of signaling is known as revertive pulsing since an originating office controls the setting of switches in a terminating office by means of pulses which "revert" back over the trunk from the terminating office. The originating office initiates only start and stop signals. Signals are transmitted by d-c technique on the trunk conductors.

When controlling a distant switch by means of revertive pulsing, the conductors of the trunk loop are closed through in the originating office as a start signal. This starts the motion of the switch in the distant office. As the switch advances over its bank terminals, revertive pulses from its commutator are sent back by short-circuiting the trunk conductors in the terminating office. These pulses are counted at the originating end of the trunk by a counter which has been previously set to open the loop when the desired number of pulses is received.

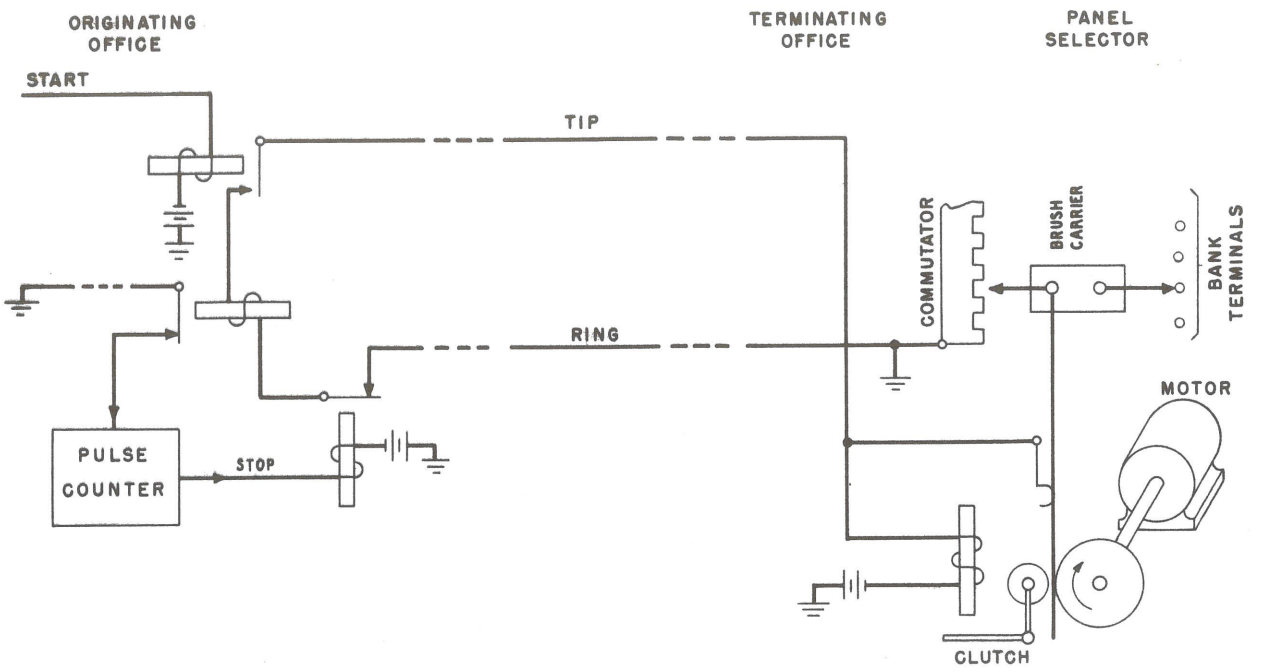


Figure 7-12 **Basic Revertive** Pulsing Circuit

Opening the loop is the stop signal which halts the motion of the switch. The basic circuit arrangement is indicated in Figure 7-12.

Revertive pulsing is also used in the No. 1 Crossbar System which does not use power-driven switches but is designed to work directly with panel offices. In this system an arrangement of relays in the terminating office starts to produce a train of revertive pulses upon receipt of a start signal from the originating office. These are counted in the originating office and also are counted by a relay circuit in the terminating office. When the stop signal is received from the originating office, the count in the terminating office is transferred to a register and the counter is released for use on the next digit.

PCI Pulsing

The initials PCI stand for "Panel Call Indicator." PCI signaling or pulsing was originally developed for transmitting information for completing a call from a panel dial office to an operator in a manual office. In this type of traffic the information from the originating subscriber is transmitted by dial pulses to the panel office and is registered on relays or switches. If the destination of the call is a subscriber in a manual office, a connection is made to a trunk to the manual office and the registered information originally received from the subscriber is transmitted to the manual operator for completing the call. In the PCI method of transmitting this information the original dialed digits are represented by PCI pulses which are received and registered on relays or switches in the manual

office and displayed on a field of lamps in view of a manual operator. The display consists of ten numbered lamps for each digit, one of which is lighted corresponding to the value of that digit. The same system is used between crossbar and manual offices and these too are known as PCI calls although not associated with the panel switching system.

PCI signals are transmitted over a dc loop and are received by means of polar and marginal relays. Four current conditions shown in the table of Figure 7-13 are used as signals. The system of coding is basically a time division multiplex system consisting of a cycle of four time intervals for each digit. One of the signal conditions is established during each of the time intervals and the combination of conditions in the four-interval cycle is arranged to represent a numerical digit according to an established code. The code uses as a basis a normal pattern of alternate open loop and light negative pulses. Each interval of this pattern is modified in exactly one way as shown in Figure 7-13. This shows that an open loop may be modified to light positive and light negative modified to heavy negative.

PCI Signal Conditions

Symbols		Loop Conditions
-	=	open loop
p	=	light positive current
n	=	light negative current
N	=	heavy negative current

(Polarities are ring with respect to tip.)

Basic PCI Cycle

Time Intervals	A	B	C	D
Normal Pattern	-	n	-	n
Permissible Modifications	p	N	p	N

Figure 7-13 PCI Signals

Two codes tabulated in Figure 7-14 are used when representing the digits of a four-digit number. These codes are of the additive type. The code for "hundreds," "tens," and "units" is a 1-2-4-5 code as shown, that is, the values 1,2,4, and 5 are assigned to modifications

	Hundreds Tens and Units				Thousands			
	A	B	C	D	A	B	C	D
Digit	(1)	(2)	(4)	(5)	(2)	(4)	(8)	(1)
0	-	n	-	n	-	n	-	n
1	p	n	-	n	-	n	-	N
2	-	N	-	n	p	n	-	n
3	p	N	-	n	p	n	-	N
4	-	n	p	n	-	N	-	n
5	-	n	-	N	-	N	-	N
6	p	n	-	N	p	N	-	n
7	-	N	-	N	p	N	-	N
8	p	N	-	N	-	n	p	n
9	-	n	p	N	-	n	p	N

Figure 7-14 PCI Codes

of the A, B, C, and D intervals respectively. The code for the "thousands" digit is also additive but it assigns the values of 2, 4, 8, and 1 respectively to modifications of the A, B, C, and D intervals. Zero in these codes is represented by the "blank" or normal pattern.

In the manual office the PCI pulses are received by polar and marginal relays and stored on register switches or relays. The fact that alternate intervals of the code are negative is used to control the synchronization of sending and receiving circuits and to advance the circuit to register successive digits in the proper intervals. Signals for a four-digit number are sent consecutively with no pause between digits and require a total time of about one second.

7.5 COORDINATION OF SIGNALING

The various types of signaling discussed in the above paragraphs are each adaptable to particular practical conditions and all are used in existing switching systems. In building up connections from one office to another, offices of different signaling types must work with each other. Often one office must work with offices of several different signaling types and the proper signaling technique must be chosen for each call.

When systems of two different signaling types must work together, one system must be adapted to work with the other by providing signal converting apparatus. The differences between two signaling systems may involve both the signal transmission technique and the codes used to represent the information.

One condition requiring its own signaling and operating procedures is where manual and automatic switching systems must work together. Calls originating in a manual office and terminating in an automatic office are handled in one of several ways. An operator in the manual office receives the called number verbally from the originating subscriber. This operator may be provided with a dial for directly controlling the switching apparatus in the automatic offices. When greater operating speed is desired, the manual operator's position is equipped with a key set which, by dc key-pulsing, controls a register and signal transmitter (sender) located in the manual office. This in turn transmits the proper type signals, such as revertive or dial pulses or MF signals, to the automatic office. MF key pulsing is also used by providing key sets and tone generators in the manual office so that multi-frequency signals may be transmitted over trunks to multi-frequency receivers in a distant automatic office. This type of traffic is often handled through a machine switching tandem office which then transmits the proper type signals to the terminating office.

Another method which is widely used requires an operator in the automatic office and permits the originating manual office to perform essentially as on full manual calls. The operator in the automatic office receives information verbally from the manual operator and transmits signals to the automatic equipment means of dc key pulses. The switchboard position occupied by the terminating operator in the automatic office is known as a cordless "B" position.

Several methods are also used for completing connections in the other direction from automatic to manual switching systems. The PCI method of signaling, previously described, is widely used and automatically transmits the proper signals to the manual office where the called number is displayed to the manual operator by means of lamps. Another method is to automatically transmit recorded verbal signals to the manual operator by means of a call announcer. The call announcer consists of a machine which continually repeats each of the ten digits, zero to nine, from sound-on-film records. The dialed number is first recorded in a register which automatically and in proper sequence for the correct digits connects the call announcer to the trunk toward the manual operator. The manual operator then hears the spoken number and is able to complete the connection as though it originated in a manual office.

Some problems in the coordination of signaling between automatic offices can be illustrated by briefly discussing the situation where No. 1 Crossbar is introduced into an area using the Panel System, such as in the metropolitan New York area. The panel system uses revertive pulsing, and information to the terminating office is transmitted in a code in which the four-digit directory number received from the calling subscriber on a decimal basis is translated to a five-digit mixed base number, each digit corresponding to a selecting action in the switching sequence of the terminating office.

	Selection	Number of Positions	Designation
1.	Incoming Brush	5	0—4
2.	Incoming Group*	4	0—3
3.	Final Brush	5	0—4
4.	Final Tens	10	0—9
5.	Final Units	10	0—9

*After incoming group selection the incoming selector hunts over 25 terminals for an idle final selector.

Figure 7-15 Panel System Selections

The panel system uses 500-point switches and a selection of one of 10,000 subscribers of an office is made through two switching stages controlled in five sequences. The 500 terminals of the first or "incoming" stage switches are divided into five banks each consisting of four "incoming" groups of 25 terminals. These 25 terminals connect to second stage or "final" selectors and the incoming switch hunts over an incoming group for an idle individual final selector. The 500 terminals of the final selectors are divided into five banks each consisting of 10 groups of 10 terminals. Thus any one of 10,000 lines can be reached by making the proper five selections in sequence. The panel selections are tabulated in Figure 7-15. The term "brush" in the names of selections refers to five bank-brushes provided on each selector, one of which is selected for use on a given connection.

The No. 1 Crossbar System was developed for areas where the panel system is in extensive use and consequently it was decided to make no changes in existing

panel equipment. The crossbar system is therefore equipped with relays which simulate the action of the panel selectors in producing revertive pulses. Thus two No. 1 crossbar offices signal to each other by means of revertive pulses in the brush-and-group code of the panel system even in areas where there is no panel equipment.

This effect of perpetuating older types of signaling or operating procedures requires a critical examination in the development of new systems. There is always an economic temptation to adapt new systems to older techniques to eliminate extensive changes of older installations. Techniques of one system are thus passed on to another and often on to a third so that the original justification for particular procedures may not even exist. Any feature of a system, such as signaling techniques and codes, which reacts on other connecting systems must therefore be carefully considered both with respect to existing conditions and the possible trends of future development.

CHAPTER 8

TELEPHONE TRUNKING

8.1 INTRODUCTION

To accomplish its purpose of interconnecting any two telephones on demand, switching requires the existence of an extensive network of linkages. One variety of these linkages is internal to the switching centers. The other variety of linkages radiates from switching centers to telephone stations and to distant switching centers. These are the outside plant linkages. The switching linkages within a switching center serve traffic to many destinations, while outside plant linkages serve traffic between two geographically separated locations.

The outside plant linkages which connect telephone stations with switching centers are the subscriber lines, while those which interconnect switching centers are the trunks. Figure 8-1 shows a simple version of the line-trunk-switching center relationship. Lines carry traffic between individual subscriber stations and their associated central offices. The trunks, on the other hand, are common arteries for traffic between the numerous local, tandem and toll switching centers.

8.2 TRANSMISSION ASPECT OF TRUNKING

The switching linkages within present-day commercial switching systems consist of paired metallic conductors. The simplest outside plant linkage for a single communication channel is also a pair of metallic conductors, generally called a loop. Although single conductor ground return subscriber lines are in use in some rural areas, most subscriber lines are of the loop variety. Short-haul trunks are also of the loop type, but advances in the transmission and signaling arts have made it possible to obtain longer-haul communication channels without employing a loop per channel. Phantom channels, mentioned in Chapter 7, were the first of this form of derived channel.

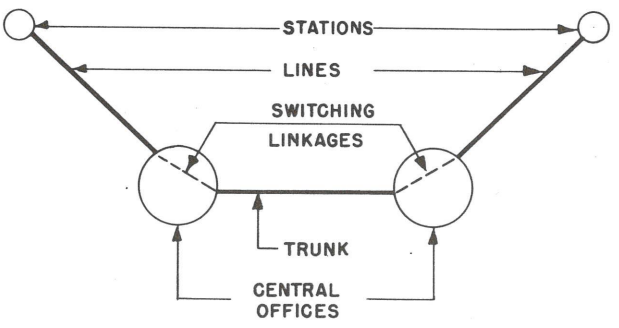


Figure 8-1 Relationship of Subscriber Lines, Trunks, and Central Offices

The extensive introduction of vacuum tube techniques in transmission

systems are providing ever increasing numbers of derived channels per loop, or its equivalent such as a coaxial cable. Carrier systems provide these additional channels per loop by frequency division, that is, by assigning a separate frequency band for each channel. Recent experiments may culminate in the use of time division multiplex methods to provide a multiplicity of communication channels. Although channels are in the main derived from wire loops, the same general techniques apply also to radio transmission.

To derive trunks which are the voice-frequency linkages, terminal equipment is provided at each end of the transmission system. The terminal equipment usually includes facilities for substituting one transmission channel for another in case of trouble, or for temporarily rearranging portions of the outside plant network.

A loop is a two-wire channel. Since transmission over long distances requires amplification at many points, and because the use of unidirectional amplifiers in a two-way transmission circuit has certain complications, it is often more economical to employ two transmission channels for a conversation, one for each direction. This type of transmission is known as a four-wire channel. Figure 8-2 illustrates a point where a two-wire transmission channel is converted into a four-wire transmission channel.

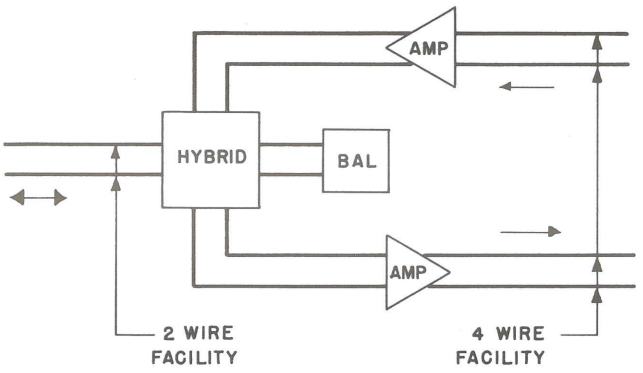


Figure 8-2 Conversion of A Two-Wire to A Four-Wire Transmission Channel

The separation of channels by direction of transmission has become common with carrier systems. Usually the four-wire channels are converted into two-wire channels where they are switched. However, four-wire switching linkages are now being used in the Nos. 4, A4A, and 4A Toll Switching Systems to permit interconnections without converting to two-wire.[1]

8.3 ONE AND TWO-WAY TRUNKS

Since trunks are capable of speech transmission in both directions, it is possible for them to serve traffic originating at either end. Trunks which are used in this manner are two-way trunks. For reasons given below, some trunks are used to handle traffic originating at only one end. Such trunks are one-way trunks.

A one-way trunk has to be marked busy only at its multipled appearances at the originating end. When a two-way trunk is seized and made busy at the

[1]Bell System Practices AB23.030—Transmission Aspects of No. 4 Crossbar Toll Switching System.

originating end, it must also be made busy automatically at its distant or terminating end. Furthermore, the trunk relay circuit at the terminating end of the trunk, upon receiving the seizure signal, must convert itself to appear as an incoming, rather than as an outgoing trunk relay circuit. These features require extra trunk relay circuit equipment. As a result of this extra equipment, which is required at both ends, two-way trunk relay circuits are more expensive than the one-way variety. Two-way trunk relay circuits may use either two or four-wire transmission facilities.

In switching between local central offices, one-way trunks are used almost exclusively. As the trunk lengths increase, however, such as in toll service, the equipment required to make a trunk two-way represents a smaller portion of the total trunk cost, and the point is reached where it is economical to use two-way trunks.

There are several traffic factors which must be considered in using two-way trunks. In general, two-way trunks are economical for small trunks groups. As the size of the group increases, the number of trunks which can be kept busy handling traffic in one direction increases. At some value of traffic, then, two one-way groups of trunks become economical, with two-way trunks used as an overflow group at either end when all the one-way trunks in the desired direction are busy. In engineering two-way trunk groups, the busy-hour traffic is obtained by adding the traffic offered from each direction. As a result, when the busy hour in each direction differs, a two-way trunk group may show further economies over two groups of one-way trunks.

8.4 EXCHANGE AREA AND TOLL PLANT

Since the cost of providing telephone service increases with distance, it is quite natural to set up different charging, operating, and administrative methods and standards for short-range and long-range service.

There are two general classes of telephone service, local and toll. (Local service is technically known as exchange area service.) The plant employed in rendering these services is correspondingly divided into exchange and toll plant. In general, the plant used for only toll service is the toll plant while all other plant is considered exchange plant. Thus cable between cities and the carrier terminal equipments associated therewith is considered toll plant. Subscriber lines are part of the exchange plant even though they are used by the subscribers in placing toll calls. Switching centers which provide local service are local central offices even though they provide the switching linkages between subscriber lines and trunks which handle inward and outward toll traffic.

8.5 INTEROFFICE TRUNKS

As stated in previous chapters, the size of a local central office is limited by practical considerations to 10,000 lines. Since many cities have more than 10,000 lines, several such switching units are required to furnish the required local service. These several units may be installed in the same central

office building or in different buildings located strategically within the city. The communication channels between these 10,000 line units are interoffice trunks or more properly interlocal trunks.

When there are several central offices in one building they may use the trunks to distant offices jointly since each of these central offices can economically indicate to the others that the trunk is busy. Since interoffice trunks in local service are usually one-way facilities, two trunk groups are established between each pair of offices. These groups need not have an equal number of trunks.

8.6 LOCAL TANDEM OFFICES, TANDEM TRUNKS AND ALTERNATE ROUTING

In large cities the number of central offices required becomes considerable. The traffic between some of the widely separated offices may be so small that few interoffice trunks are required between them. Such small trunk groups are inefficient. Economies therefore result in providing switching units for trunks between local central offices. These switching units are local tandem offices. With local tandem offices, small interoffice trunk groups between distant local offices in the same city may be completely eliminated by providing each office with trunks to and from the tandem office.

Local tandem offices serve several other trunking purposes. By providing an automatic alternate routing feature in the local switching offices, calls may be normally routed over direct interoffice trunk groups, but should these all be busy, they can then be routed via the tandem office. In this way the direct interoffice trunk groups may be engineered to be kept busy a large percentage of the time, and the traffic peaks at the busy hour are carried through the tandem offices. As previously mentioned, traffic peaks to and from different offices do not necessarily coincide and hence the load on the tandem office and on the trunks to the tandem office may even out with respect to time.

Another trunking use of local tandem offices is to provide access to trunks to nearby toll areas. These toll areas are reached by what is known as the AB Toll operating method. In this method calls are extended via the local tandem office beyond the limits of exchange area service by employing local operating methods. Local tandem offices may be also used to handle inward long-haul toll traffic, since they usually have access to trunks to all local offices in an exchange area. Tandem offices are sometimes used to concentrate trunks to special facilities such as to time-of-day and weather announcing facilities.

Tandem switching offices are mostly located in buildings with regular local central offices. In such cases the trunks to distant offices may be used jointly by the local central and tandem offices.

Trunks carrying traffic to local tandem offices are local tandem trunks. Trunks carrying traffic from local tandem offices are tandem completing trunks. In some cases more than one local tandem office may be used within an exchange area. Each tandem office need not have trunks to all local offices. Some calls may, therefore, pass through more than one tandem office. Figure 8-3 illustrates the trunk relationships of a tandem office and three local offices.

8.7 TOLL TRUNKING

With local tandem trunking, the scope of the telephone subscribers direct calling range is extended to any point within a large metropolitan area, including short-haul (AB) toll calls handled on local switching basis. Long-haul toll service to distant cities necessitates the use of different operating methods, more complex trunk circuits and more complex features in the switching centers.

As a result, toll switching offices are established within larger cities. These toll central offices or toll centers switch direct toll traffic between the surrounding local exchange area and the toll centers of other areas. They may also act as switching centers for through or multi-switched toll traffic between distant toll offices. There are some 2500 toll centers in the Bell System which serve the more than 18,000 local exchange areas.

Toll connecting trunks connect local central offices with toll central offices. Trunks used for originating toll traffic are known as recording-completing trunks since it is over these trunks that the toll operator records the call, and they are retained as one link in the completion of the desired connection. Recording-completing trunks appear before what is known as an outward or combined line and recording (CLR) toll operators. With manual toll switching, this operator may have direct access in the switchboard to trunks to distant toll central offices. These trunks are intertoll trunks. Intertoll trunks are frequently two-way trunks, carrying traffic originating at outward operator positions at either end and terminating at inward or through operator positions at each end. The inward toll operator completes calls to the desired local central office over a toll switching trunk. Figure 8-4 illustrates the relation of these three types of trunks and toll switching centers.

The number of intertoll trunks required at a toll center may be so large that they cannot all be placed before all outward and through operators. As a result toll tandem switching units are provided at large toll centers to receive, over toll tandem trunks, requests for intertoll trunks. The application of

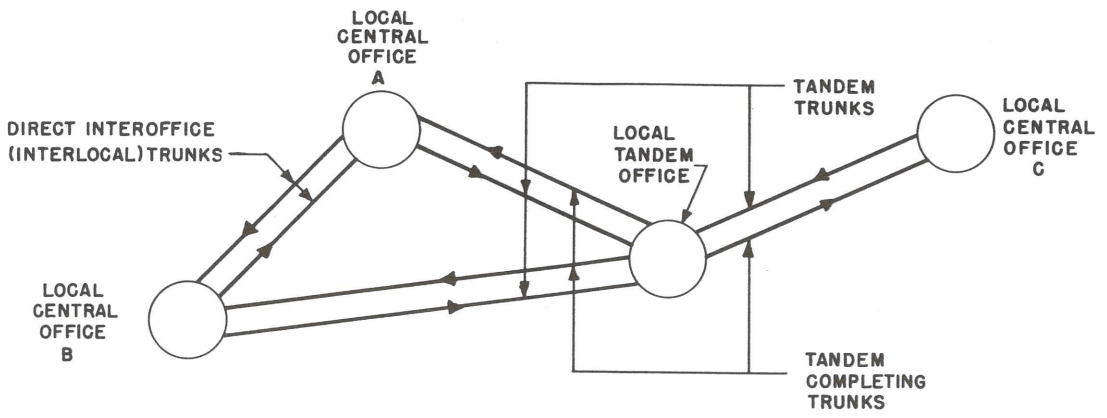


Figure 8-3 Typical Trunking Interconnecting A Local Tandem and Three Local Central Offices

automatic switching to toll traffic increases the use of toll tandem trunking. This automatic toll switching equipment may be located in the same building as the outward toll switchboard or at some distant point. By using toll tandem operation, particularly with automatic toll switching, local operators are enabled to handle many toll calls on a decentralized toll operating basis. The toll tandem trunks before a local operator afford access to the entire toll network radiating from the toll switching center.

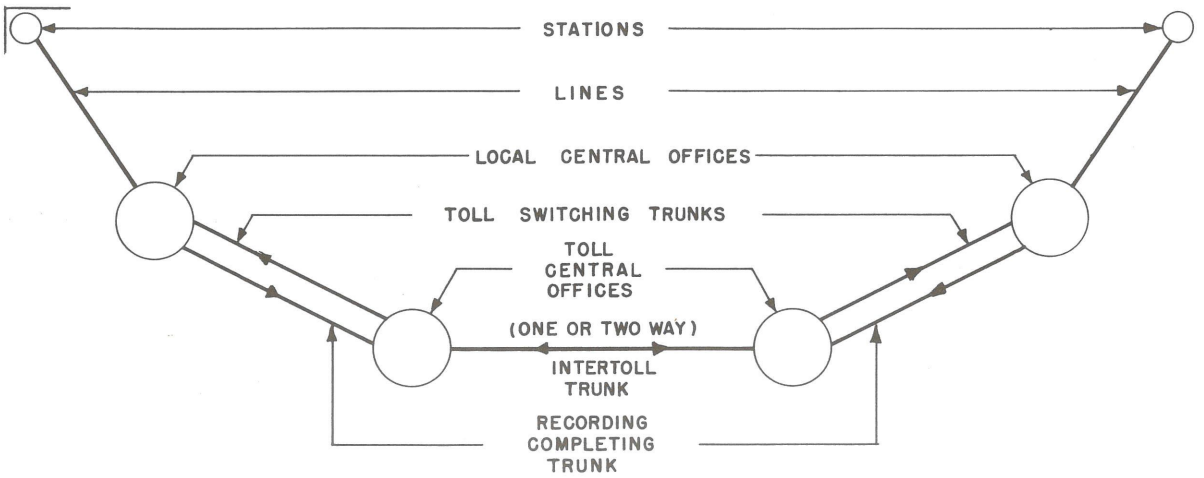


Figure 8-4 Relation of Trunks to and From Toll Central Office

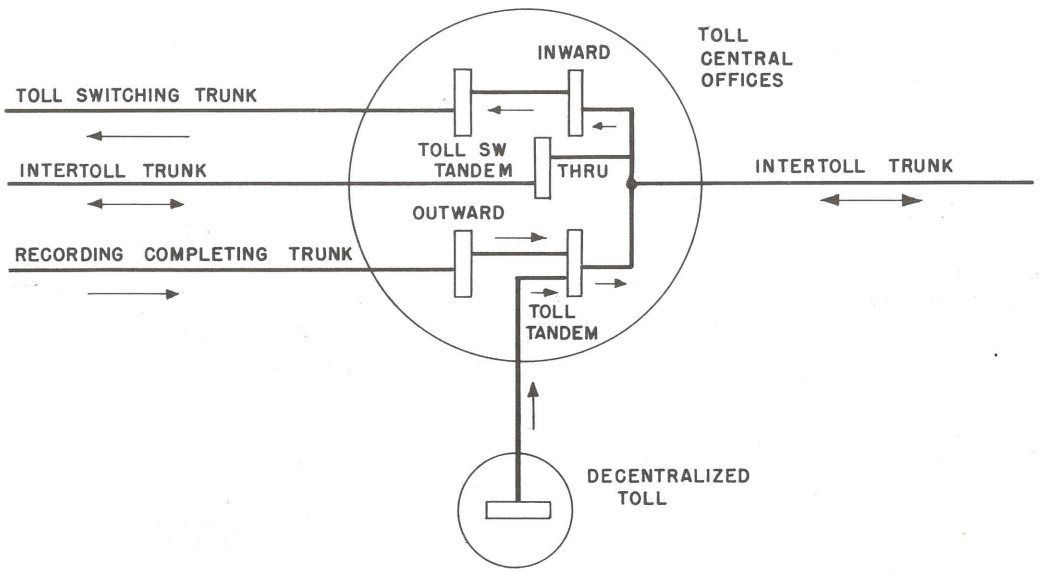


Figure 8-5 Relation of Various Switching Units in a Toll Central Office

In large manual toll centers toll switching trunk tandem switchboards are sometimes necessary to enable the inward operator to obtain access to toll switching trunks to all offices served by the toll center. Since local tandem offices frequently have trunks to all local central offices served by a toll center, local tandem offices may also be used to complete toll calls over tandem completing trunks. Figure 8-5 shows the switchboard and trunk relationships in a toll central office.

8.8 GENERAL TOLL SWITCHING PLAN[2]

The General Toll Switching Plan is a basic toll trunking plant layout designed for the highest practicable standards of service consistent with economy. It takes into consideration interconnecting speed, directness of routing between any two points in the country, and suitable transmission standards. On multi-switch calls its object is to reduce the number of switching points required, and to put a ceiling on the maximum.

The plan calls for direct intertoll trunks from each toll center to at least one larger and strategically located toll center known as a primary outlet. There are some 150 primary outlets in the General Toll Switching Plan. Primary outlets serve the toll centers of the surrounding area. Thus toll service may be given within an area served by a primary outlet with a maximum of two outside plant toll linkages.

Eight of the most important primary outlets are designated as Regional Centers. Regional centers are toll switching offices strategically located to cover various regions of the country and all are completely interconnected by direct intertoll trunks, thus forming the backbone of a countrywide toll network.

Primary outlets have direct intertoll trunks to at least one regional center. An intermediate toll center classification, Secondary Outlet, is applied to certain toll offices which serve as alternate routes between toll centers and regional centers.

Cities which are not large enough to be toll centers, may be served by a tributary toll office, with direct trunks to a nearby toll center.

In its most elementary form the plan takes the pattern of Figure 8-6. An analysis shows that an intra-regional call need pass through no more than five toll offices over four intertoll trunks, and the maximum for an inter-regional call is six toll offices over five intertoll trunks. When justified by traffic, the basic routes of the general plan are supplemented by direct intertoll trunks between toll centers or primary outlets in the different regions. These supplementary routes are also used to reduce considerably the length of some connections which, if set

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[2] H. S. Osborne, General Switching Plan for Telephone Toll Service, Bell Telephone System Monograph B485.

up in accordance with the basic general plan, would result in objectional back-haul.

The intertoll trunks for this general toll switching plan may be of the terminal or via or common grade. In general, terminal grade intertoll trunks are only satisfactory for single-link traffic between two toll centers. Traffic requiring two or more intertoll trunks in series are established over via grade trunks. The common grade trunks are used for either single-link or multi-link traffic. A common grade intertoll trunk group may be provided as an overflow group for separate terminating and via groups.

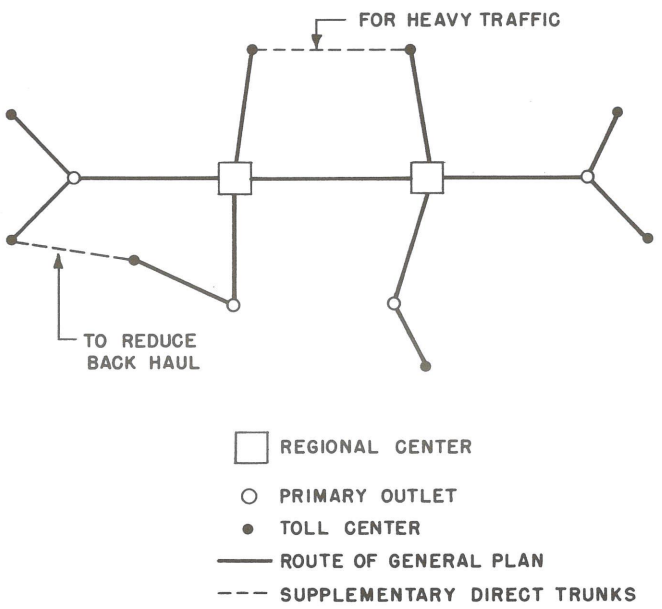


Figure 8-6 Schematic of General Toll Switching Plan

8.9 NATIONWIDE OPERATOR TOLL DIALING[3]

The trunking embodied in the general toll switching plan is being modified for use with automatic toll switching equipment. With automatic toll switching, only the CLR operator is needed to record the pertinent details of a toll call and to send control signals to the switching equipment which then functions to route the call automatically to its destination.

The trunking plan for nationwide dialing[4] follows in principle the general toll switching plan. A new national switching center is, however, contemplated to handle traffic overflowing from the direct trunk groups which interconnect regional centers. Furthermore, sectional centers are interposed in the backbone trunking network between primary outlets and regional centers.

Primary outlets, sectional centers, regional centers and the national center will be control switching points (CPS). These control switching points are to be equipped with common control switching systems to determine automatically the call routings from the national area and office codes and to establish the connections over direct or alternate routines according to a predetermined routing plan. Four-wire switching linkages will be provided within the control switching points.

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[3] Letter to Chief Engineers, May 10, 1946—Nationwide Toll Dialing With Attached Notes.

[4] General principles of Nationwide Dialing, January 17, 1947—Case Folder 33502-11.

The principles of automatic alternate routing permit engineering of inter-toll trunk groups in one of two classes: high usage groups and final groups. High usage groups provide fewer trunks than are necessary to handle the peaks of busy-hour traffic between two points with satisfactory service grade. They do, however, handle a large proportion of the total traffic offered. Final trunk groups are liberally engineered and constitute the basic trunking framework interconnecting all toll centers. Final trunk groups will connect: regional centers with the national center, every sectional center with its home regional center, every primary outlet with its home sectional center, and every ordinary toll center with its home primary outlet. A toll center may have direct groups of trunks to several other toll centers and CSP's, but each toll center is tied into the backbone network by a final group to one particular primary outlet. Figure 8-7 shows the maximum possible routings between two ordinary toll centers. Each of these alternate routes may not necessarily exist between two points, but the numbering of the routes indicates the order in which each trunk group is automatically tested and used by the automatic toll switching equipment.

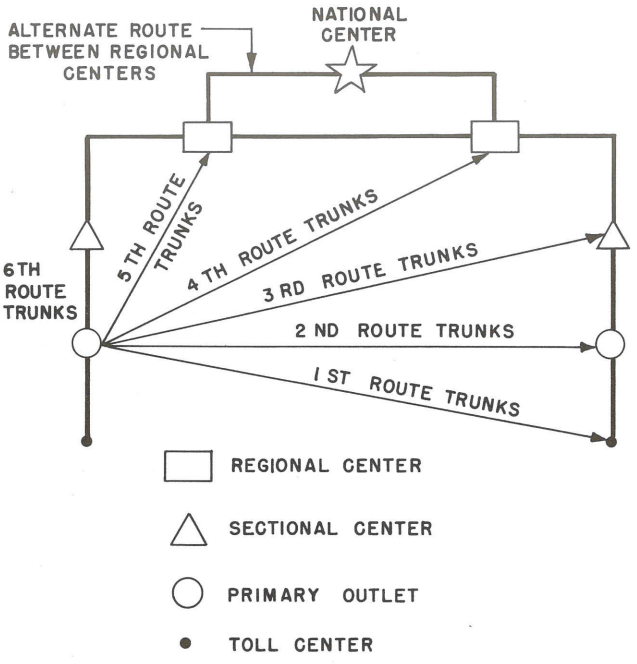


Figure 8-7 Trunking and Automatic Alternate Routing Plan for Nationwide Toll Dialing

CHAPTER 9

TRANSMISSION AND AUXILIARY FEATURES OF SWITCHING SYSTEMS

9.1 GENERAL

The ultimate purpose of switching is to set-up, on request, a voice transmission path between two telephones. An ideal telephone switching system would therefore function to simply interconnect sections of available transmission channels to satisfy this purpose, without itself influencing the characteristics of the channels. In practical switching systems, however, the separation between transmission and switching means is not nearly as complete as the ideal system implies. Certain features of switching systems which are primarily dictated by transmission considerations will, therefore, be briefly discussed in this chapter. These include both negative and positive actions that may be taken; that is, negative in the sense of preventing switching facilities from interfering with the characteristics of the transmission channels, and positive in the actual switching of components solely for transmission reasons.

In addition to the transmission considerations, practical switching systems must perform functions which are not integral parts of the basic job of interconnecting two specified telephones. In fact, some of these extra functions stem from the inability of a switching system to do its primary job under certain conditions. The facilities such as those that are provided to dispose of calls that cannot be completed to the desired point are the auxiliary switching features. Finally, in addition to the auxiliary features, switching systems have practical adjuncts which owe their existence to the fact that telephone switching systems must fit subscribers' service and economic requirements and be profitable enough to survive and progress. Auxiliary features are discussed in this chapter in addition to transmission considerations. Practical adjuncts are taken up in subsequent chapters.

9.2 TRANSMISSION CONSIDERATIONS:

Losses

Figure 9-1 is an elementary representation of sections of transmission paths that are connected into a continuous voice transmission channel by a switching center. Figure 9-2 is a somewhat more detailed representation of a completed transmission channel in a local connection.

Figures 9-1 and 9-2, however, do not indicate any provision for setting-up, holding, and disconnecting at the appropriate time, the voice channel. Economy

dictates that especially in the outside plant the voice transmission paths serve also as the vehicle for passing this control and supervisory information from the subscriber telephone to the central office, and from one central office to another. This dual use of the transmission channel makes the various linkages an integral part of both the switching and transmission systems. Inherently no conflict exists between the transmission of voice currents and control signaling because of the time sequence involved. Conversation over a channel is not begun until the interconnection is completed between the required telephones and, at this time, control signaling has performed its function.

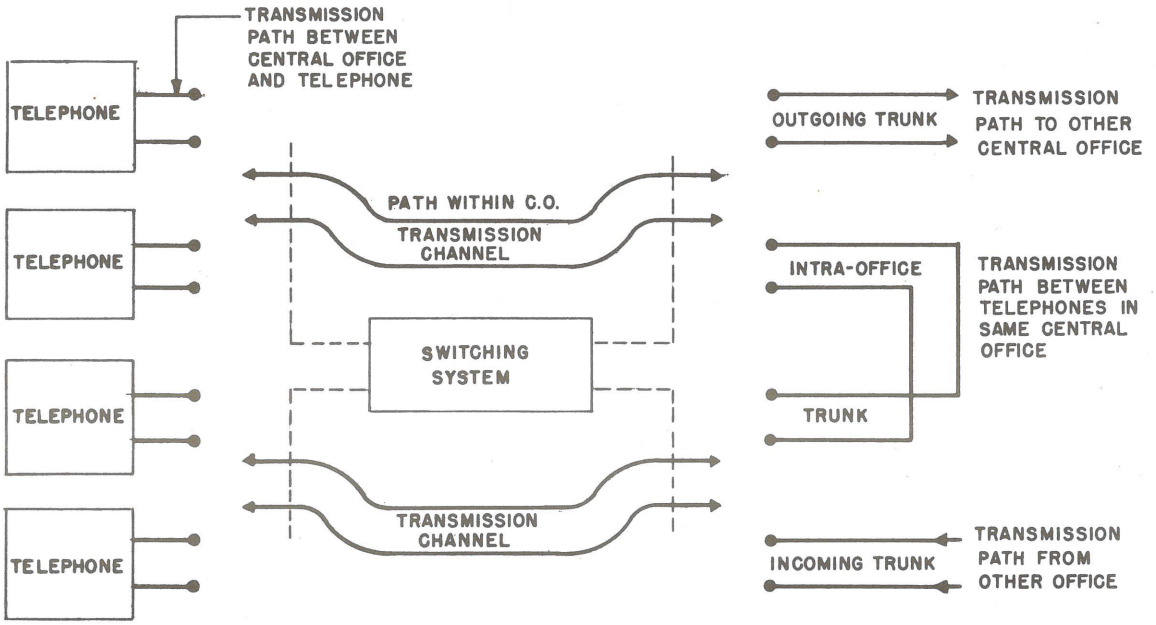


Figure 9-1 Switching and Transmission

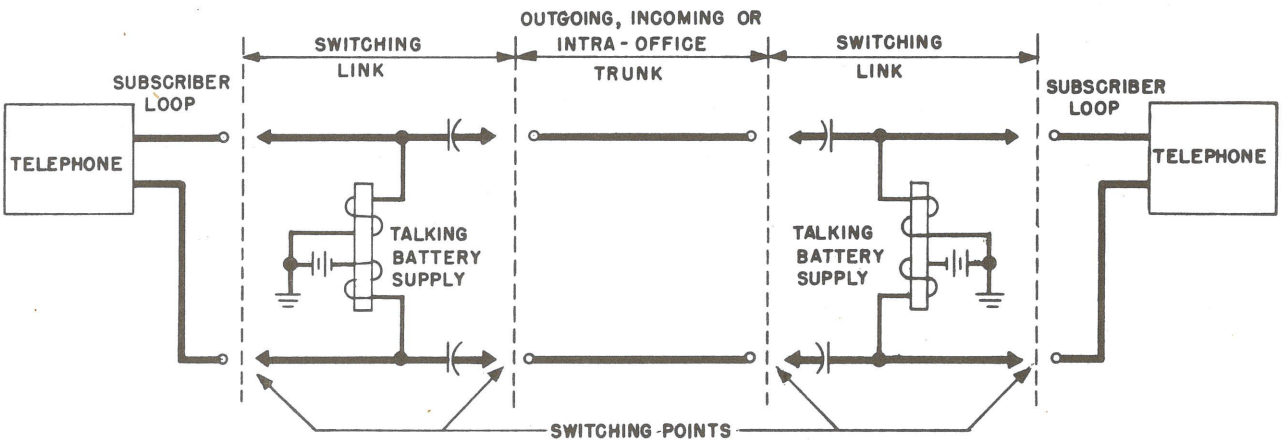


Figure 9-2 Transmission Channel (Local Call)

Supervisory signaling, however, must be considered as inherently interfering with voice transmission because these signals come into play after a connection is established and is being held for conversation. To achieve, in practice, non-interference of supervisory signals with voice transmission on the same channel requires that the former be held outside of the audible range during the conversation time. Direct currents are therefore used mostly for supervision, being applied or removed before or after conversation time. Supervisory signals in toll switching systems are sometimes alternating currents within the voice-frequency range. Here, prevention of interference with voice transmission is accomplished by a form of "negative control," in that the supervisory signals are impressed on the circuit only during non-conversation time.

The dual usage of the transmission channel introduces switching apparatus in the transmission path, as shown in a simplified way on Figure 9-3.

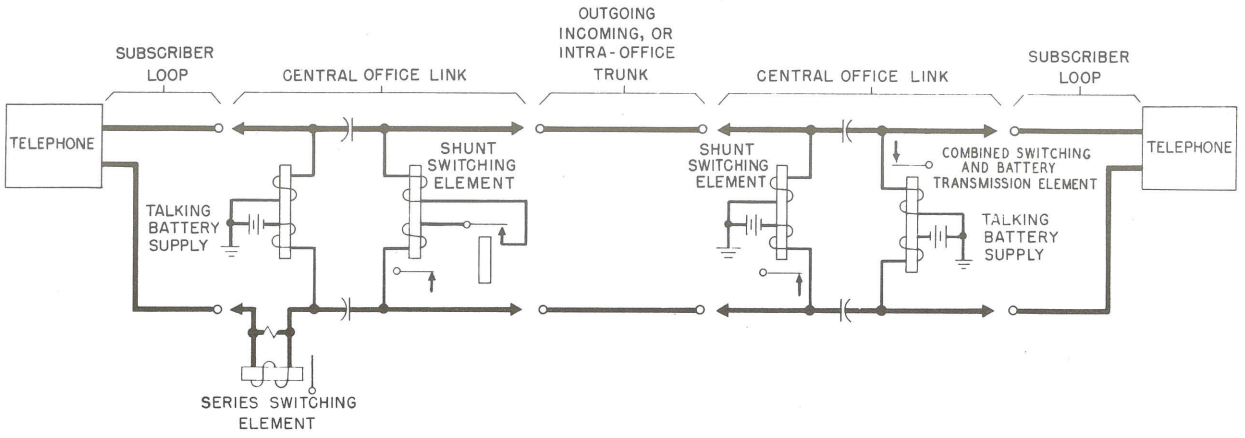


Figure 9-3 Switching Elements Applied to Transmission Channel

The switching apparatus appear either as shunt or series impedances to the voice currents. Such impedances could cause transmission loss and distortion, the magnitude of each depending upon the electrical constants of the elements and the manner in which they are connected in the transmission path. Impedances which are substantially linear over the voice frequency band-width, such as non-inductive relay windings, will cause only attenuation. Reactive impedances, however, may cause frequency and phase distortion as well. Transmission considerations require, then, that the number of these impedance elements, inserted in the transmission path by switching, be kept at a minimum and have suitable characteristics*.

*C. M. Morris, Transmission Schematics of Central Office Circuits MM-483400-79, September 2, 1948.

Interference

In switching design, transmission considerations extend beyond the prevention of attenuation and frequency distortion of voice currents. The process of establishing connections must not cause interference with conversation on established connections. The switching plant must, therefore, be designed to introduce no noise, clicks or crosstalk. In general the pairing and transposing (twisting) of the transmission conductors forming the talking paths, the use of metallic transmission paths, filtered power feeds, segregated noisy leads, and the like, adequately minimize such interference.

The reverse interference, that is, the interference of transmission with switching, is also a factor in switching design. Voice-frequency signal receiving equipment, for instance, has to be guarded against false operation due to voice currents.

Switching of Transmission Components

The above discussed transmission considerations were negative in their effect upon switching system design, inasmuch as a prevention of degradation of facilities was primarily involved. When transmission circuits are, however, extended over long distances, such as in toll plant, additional considerations of a more positive nature are involved. These entail the performance of actual switching operations for specific transmission reasons. The necessity for switching transmission components results from the objective of providing reasonably uniform transmission in spite of the variable number of transmission links (intertoll trunks) that may be utilized in making up the voice channel. As shown in Figure 9-4, these links vary not only in number, but also in transmission grade.

When two or more intertoll trunks are thus switched together to make up a complete channel, as shown from subscriber K to subscriber Z in Figure 9-4, the total transmission loss becomes the sum of the individual losses. To keep this cumulative loss within narrow limits, switching systems are called upon to have one of two features.

1) Repeater Switching

In some systems, transmission gain is introduced automatically by the switching system by the insertion of an amplifier or repeater. This repeater is inserted upon ascertaining the need for it from information as to the type of incoming trunk and the destination of the call.

2) Pad Switching

When intertoll trunks, for transmission economy reasons, include repeaters at their terminals, switching systems reduce the transmission loss of a trunk-to-trunk connection by removing a loss-producing network, commonly referred to as a pad. The removal of the pad is controlled directly by information from the connected trunks. This more simple operation is illustrated in Figure 9-5. Two

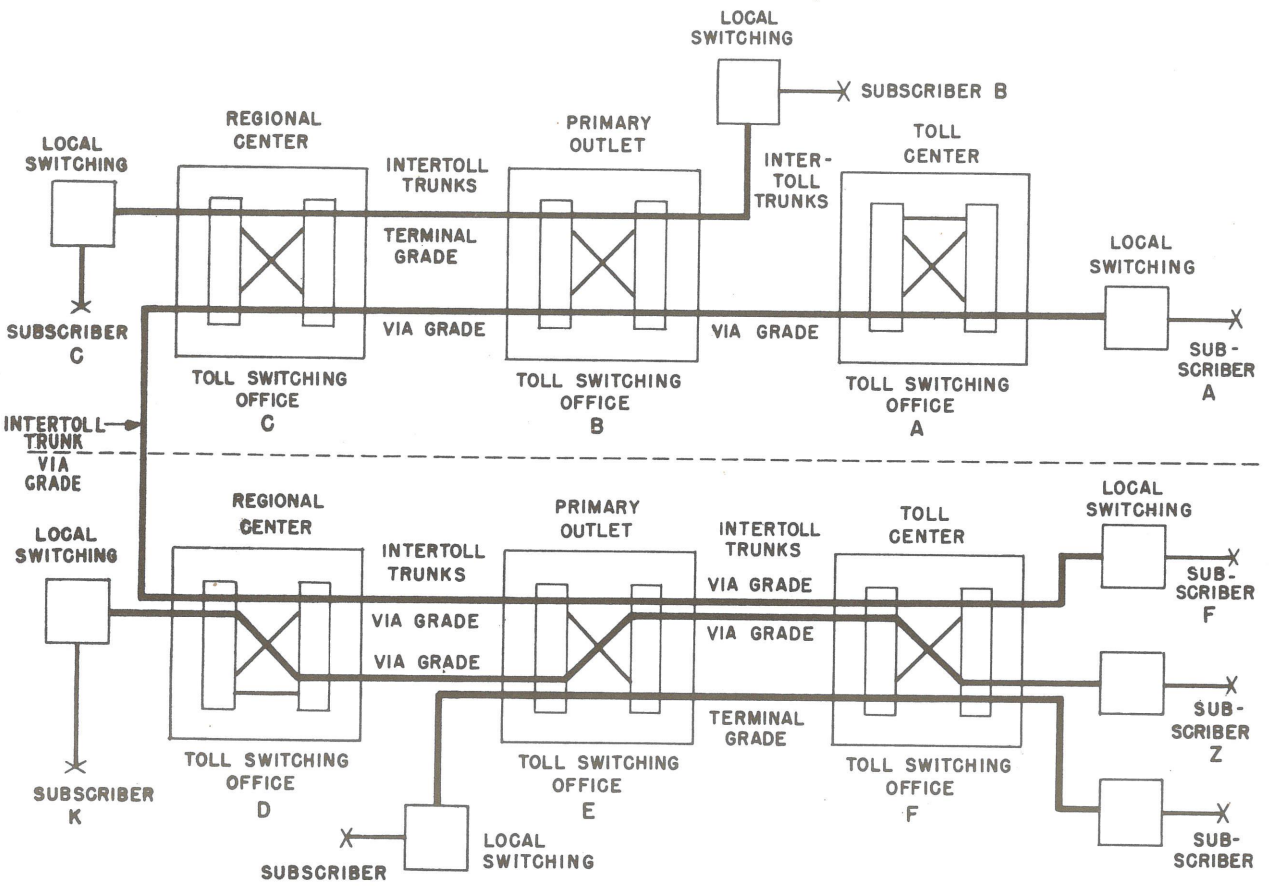


Figure 9-4 Transmission Aspects of Toll Switching—Examples of Channel Make-up

intertoll trunks are shown, Figure 9-5A demonstrating a terminal* condition of one trunk, and Figure 9-5B a via condition for both trunks.

Switching of Intertoll Trunks of Various Transmission Grades

Switching system features involving transmission considerations of intertoll trunks include means for handling split grade trunk groups. This requires the automatic choice of only via-grade trunks for multi-link connections, and terminal grade trunks for single-link connections. If the third or common grade trunk group is provided, traffic for either of the first two grades will automatically overflow into the common grade group.

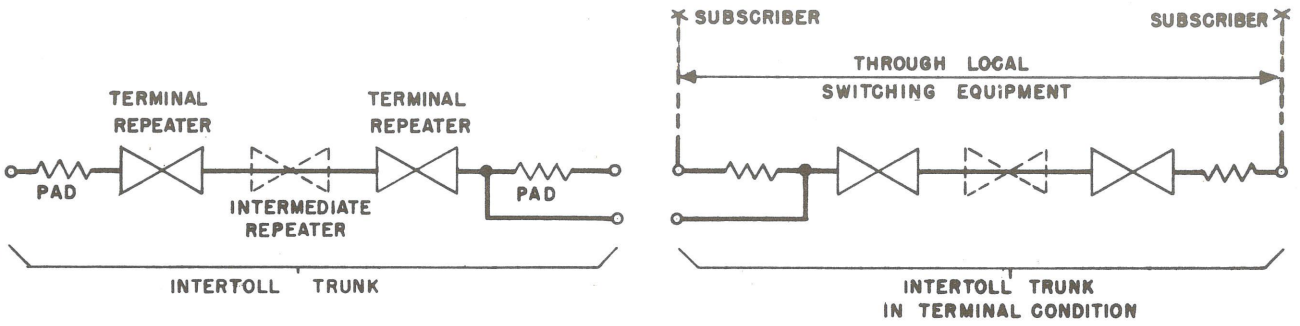
*When an intertoll trunk is terminated at both ends by local switching equipment and subscriber lines, it is in a terminal condition. When it is one of several links it is in a via condition.

9.3 AUXILIARY FEATURES

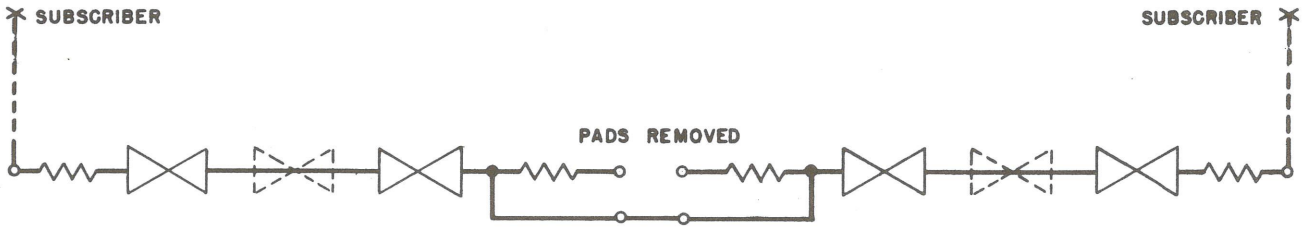
Disposition of Calls

Switching systems, in general, must provide for the disposition of calls which cannot reach the desired destination. Calls may fall into this class because the switching system may not receive sufficient information to identify the wanted destination, or because a blockage is encountered. The first instance usually results from improper dialing, while the second is generally caused by paths-busy conditions. Such calls that do not reach their destinations are referred to as lost starts.

The orderly disposition of all types of lost starts is a necessary feature in switching systems, first from the standpoint of the calling subscriber, and second as a means for allowing control equipment to perform its function without delay and proceed to handle other calls. The disposition of lost starts requires the provision of auxiliary features in the form of appropriate artificial destinations such as overflow, permanent signal, intercept trunks, and the like, which, beside forming a depository, furnish informative tones to the calling subscriber or connect an assist operator. Connections to trouble alarms, registers for statistical purposes, and so forth, may also be provided as adjuncts.



(A) INTERTOLL TRUNK IN TERMINAL CONDITION WITH LOSS PADS INSERTED



(B) INTERTOLL TRUNKS IN VIA CONDITION WITH GAIN INSERTED (PADS REMOVED)

Figure 9-5 Pad Switching

Examples of the tones furnished subscribers as informative tones are listed below. Any particular switching system may not necessarily furnish all of them, and in certain systems the characters of some of these tones may be identical.

Overflow Tone—Indicates that needed trunks or connecting paths in the switching system are all busy.

Partial Dial Tone—Indicates that, as far as the switching system is concerned, dialing has not been completed within a preallotted time measured from receipt of dial tone.

Permanent Signal Tone—Indicates that, as far as the switching system is concerned, no dialing has been done within a preallotted time.

Vacant Code Tone—Indicates that the office code dialed is a nonassigned code.

No-Coin Tone—Indicates that the customer at a coin telephone has not deposited the required coin.

No-Such-Number Tone—Indicates that the number dialed is not assigned to a subscriber.

Reverting Tone—Indicates that the called subscriber is on same line as the calling subscriber.

In contrast, two other tones are mentioned below which are used, in general, if the call reaches its required destination*. These two tones are:

Audible Ringing Tone—Indicates to the calling subscriber that the bell of the called subscriber is being rung.

Busy-Signal Tone—Indicates that the called subscriber line has been reached but is busy on another connection.

Assist Services

Calls to changed or recently disconnected telephone numbers, or numbers with the associated lines out of service, are disposed of in dial switching systems by automatically connecting them to an intercept operator. This operator assists the calling subscriber by providing information as to the number change, correctness of dialed number, or by furnishing the information that the call cannot be completed for a stated reason.

Zero Operator and Information Centers

In addition to intercept service, assist service is rendered by a zero operator for completion of calls which cannot be dialed because of unusual conditions, or for calls terminating in zones which are not in the dialing area of the

*Dial Tone, although it may be classed as conveying information to the subscriber, is required as an integral part of certain switching systems in their basic function of setting-up subscriber-to-subscriber connections, and for this reason has not been included in the above list.

calling subscriber. To aid the subscriber in reaching a zero operator under any condition only one digit, "zero," is dialed. The switching system must recognize, upon receipt of the initial zero, that only this one digit is necessary and proceed with a connection to a trunk to the zero operator.

Other types of assist calls which switching systems are designed to complete on the basis of fewer digits than regular calls are those for long-distance operators, information centers, repair centers, and so forth.

Delayed Toll Traffic Handling

Other examples of auxiliary features may be taken from toll switching systems. For instance, for economic reasons, long-distance intertoll trunks are engineered for higher values of lost call probabilities than short haul trunks. This necessitates repeated attempts by an operator with a waiting call to secure a trunk during the busy hour.

Auxiliary features which reduce this necessity of making repeated unsuccessful attempts are a part of toll switching systems. These features comprise such facilities as overflow trunks and control circuits, and master busy trunks.

Overflow trunks and control circuits, which individually may handle a number of simultaneous connections, are associated with their respective intertoll trunk groups and serve in a call-storing and group-busy information capacity. A call encountering an all-busy intertoll trunk group situation is connected to the associated overflow trunk and control circuit. As long as all intertoll trunks in the group remain busy, the overflow trunk and control circuit returns an appropriate informative signal, visible to the originating operator, on all the connected calling circuits. When an intertoll trunk in the group becomes idle, the visual informative signal is changed accordingly. A waiting operator who is ready, may then proceed to complete the call.

When the overflow trunks, which provide storage facilities for all calls having a reasonable chance to be served in a few minutes, become fully occupied, further calls are connected to one of several master busy trunks common to the switching office. Master busy trunks return a distinctive informative signal.

In cases of unusual demand, certain intertoll trunk groups may experience heavy overloads for extended periods. Under these conditions, the objective is still to serve the calls in the sequence of their filing time, and to inform the originating operators of the expected time delay. Such calls are served at call-order switchboards. Under control of this board newly originated calls are excluded from access to the overloaded trunk group until the delayed calls have been served on the filing time sequence basis.

Under these conditions of severe congestion delay quoting trunks are connected to the overflow trunks and control circuits and the normal informative signals are disabled. These delay quoting trunks appear on the call-order switchboard and provide means for quoting the expected delay by call-order board operators.

CHAPTER 10

PRACTICAL ADJUNCTS TO SWITCHING SYSTEMS

10.1 GENERAL

In addition to the basic requisites discussed in Chapter 3, and the auxiliary features outlined in the preceding chapter, a group of extraneous requirements is imposed on switching systems: to furnish various types of telephone services in accord with subscribers' agreements, to offer certain customer conveniences, to economize on operation and maintenance costs, and to increase the reliability of over-all performance. This group of requirements may be considered as adjuncts to switching systems in that they do not directly enter into the primary or auxiliary functions of establishing a communication channel between two individuals. That they do, however, have a substantial effect upon these functions will be developed on the following pages.

Practical adjuncts to switching systems are exemplified by: private branch exchange service provisions, public pay stations, party line services, assistance rendered by intercept, information, and zero operators, testing and maintenance facilities, subscribers' service metering arrangements, and so forth. These adjuncts are, of course, not all required by every central office installation. The need for them depends upon local conditions.

In this chapter conditions creating the necessity for certain adjuncts will be briefly described and examples discussed. Adjuncts which are major subjects in themselves, such as the charging features in switching systems, will be covered in separate chapters.

10.2 SUBSCRIBER'S LINE CONSIDERATIONS—INDIVIDUAL LINE

Basic Line

Subscribers' telephone services are of several types. Typical classifications include individual or party lines, flat-rate, message-rate or coin service, residential or business categories, limited or extended scope service. Each of these classes implies specific operating procedures of the central office switching equipment in processing originating or terminating calls. It is these variations in operating procedures which require functions to be performed by the switching system which are not basic to switching. Prior to the discussion of the effect of these variations upon the switching system, a clearer understanding of the

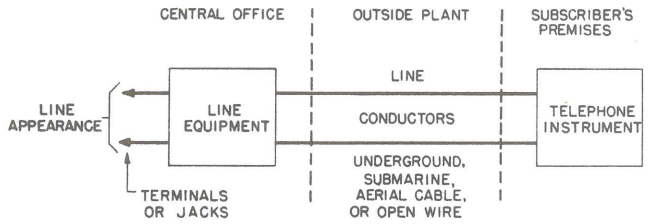


Figure 10-1 Basic Telephone Line and Equipment

principles involved will be obtained by examining the actual components of a subscriber's basic line.

The equipment, individual to a subscriber, over which the origination or completion of a call is made appears in three places: on the subscriber's premises, in the outside or cable plant, and within the central office. Within the central office, as shown in Figure 10-1, the line has access to the switching equipment (or vice versa) by means of terminals on automatic switching equipment or jacks on manual switchboards. Associated with this line appearance is a simple circuit, referred to as the line equipment, which enters into the origination and completion of calls from and to the line. Outside the central office are two conductors, which extend from the central office to the subscriber's premises. Connected to this pair at the subscriber's end of the line is the subscriber's set which comprises transmission and signalling means.

Individual Service—Flat-Rate, Message-Rate and Coin

The subscriber's set, line, and line equipment mentioned ahead are the basic components which could be furnished to all persons subscribing to telephone service, and the cost of furnishing such service could be divided equally among the subscribers. Such service, when furnished, is known as individual flat rate; individual because each subscriber has exclusive use of a line and line equipment, and flat-rate because of the fixed flat service charge. This service requires no additions to or modifications of the basic switching functions.

Service, however, as mentioned earlier, may also be furnished subscribers as measured, that is, charged for on the basis of the number of messages originated. Such service is classed as message-rate service, and requires a modification of the basic line to accommodate apparatus for metering purposes. The commonly used meter is the message register, connected as shown in Figure 10-2.

This measuring device is under control of the switching system, which may ascertain the completion of calls and cause the meter to score. Additional functions, thus, must be performed by the switching system in controlling the meter. In fact, the subscriber's service metering features are so extensive that their full discussion is deferred to Chapter 11.

To furnish service mainly to non-subscribers, telephones with associated coin boxes are available in public places. These Public Pay Stations furnish

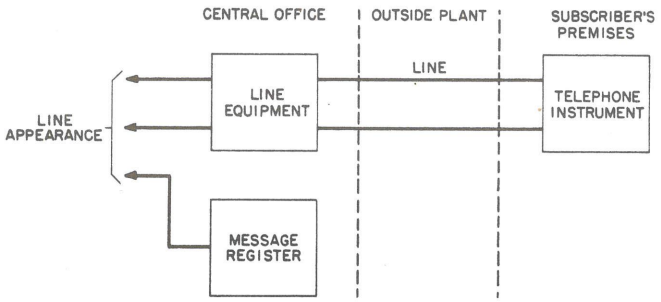


Figure 10-2 Basic Line Modified for Message-Rate Service

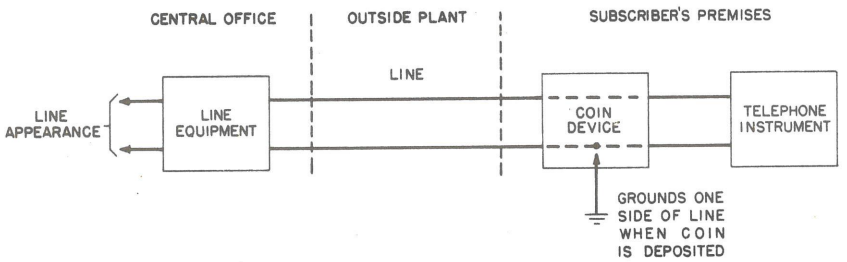


Figure 10-3 Basic Line Modified for Coin Service

telephone service on a cash basis. Modifications of the basic subscriber's line are required to use a coin collect or return device as shown in Figure 10-3. The switching system must, in turn, add additional features for the detection and control of the coin, as described in Chapter 11.

The above are examples of different classes of originating service which require identification of the type of calling line. The switching system must be able to recognize this identification and react accordingly. This class identification, however, is not limited to originating conditions. It will also be found, in the following pages, to play an important part in the termination of calls as well.

10.3 SUBSCRIBER'S LINE CONSIDERATIONS—TERMINAL HUNTING

Consecutive Grouping of Lines to One Subscriber

In the case where one individual telephone may not be sufficient to accommodate both the incoming and outgoing traffic requirements of a subscriber, several

separate individual lines may be installed. A method of handling the problems inherent in such a grouping was worked out in manual switching systems and may be illustrated as follows:

Consecutive directory numbers, such as 0100, 0101, 0102, and so forth, were assigned to the lines of the same subscriber. The associated line-jack appearances would then be adjacent to each other in the manual switchboard jack field as shown on Figure 10-4. These associated line-jacks were "grouped" by painting the face of the switchboard about these jacks a distinctive color, as shown on Figure 10-4 for two groups, 0100 to 0103 and 0125 to 0127. Incoming calls were directed to these groups by passing only the first directory number to the operator. The operator, upon locating the received directory number, would immediately recognize that the line was part of a group, and if busy, select the first idle line in the group to complete interconnection. If all lines in the group were busy, the calling subscriber would be so informed. This type of operation was known as consecutive hunting because the grouped lines are hunted over in a consecutive sequence for an idle line. Automatic switching systems are required to perform a similar operation when terminating a call to grouped lines.

Grouped lines are not confined to individual telephones. They may serve wiring plans which enable the connecting of one of several subscriber's lines to any one of several telephones on the subscriber's premises, or they may serve private switching centers located on the subscriber's premises which may connect from a few to several thousand telephones on the subscriber's premises to each other or to grouped subscriber's lines. Grouped lines feeding private switching centers are usually termed Private Branch Exchange or briefly PBX lines. These lines are generally two-way, that is, calls may be either originated or completed over the lines PBX line groups may range in size from a very few to several hundred.

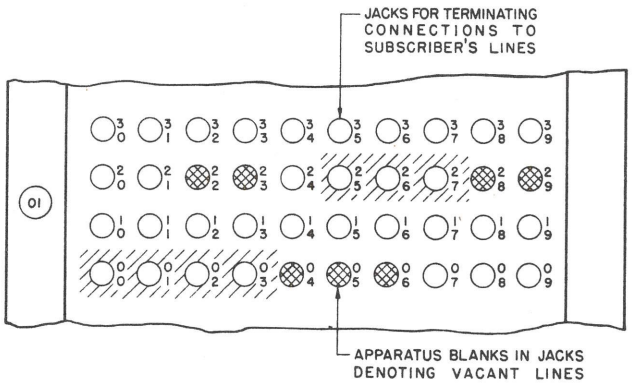


Figure 10-4 Section of Manual Switchboard. Line Appearances in The Form of Jacks For Completion of Calls. Lines 0100 to 0139 Shown. Note Grouping of Lines 0100 to 0103 Effected by Painting Face of Board a Distinctive Color Around Jacks. Note Also Vacant Lines.

PBX line hunting is, of course, a requirement of convenience in small groups and an absolute necessity in large groups; and as such must be included in switching systems. The seemingly simple operation, as outlined above, has created one of the major problems in switching system design because it incorporates an additional selection beyond those normally provided in the system for all calls.

PBX hunting considerations require that all terminating

appearances except the last in a group be identifiable to the control and busy test functions of the switching system as belonging to a PBX group. The control circuit must be stimulated by this identification to a change in normal routine only when a line busy condition is encountered. Upon receipt of a busy condition of the first line in the group, normal busy reporting procedure must be deferred and a test of the second line instituted. This test must continue, line by line, if intermediate lines are found busy, until the last line is reached. The last line of the group allows the control function to revert to its usual routine, returning a busy report if this line is busy.

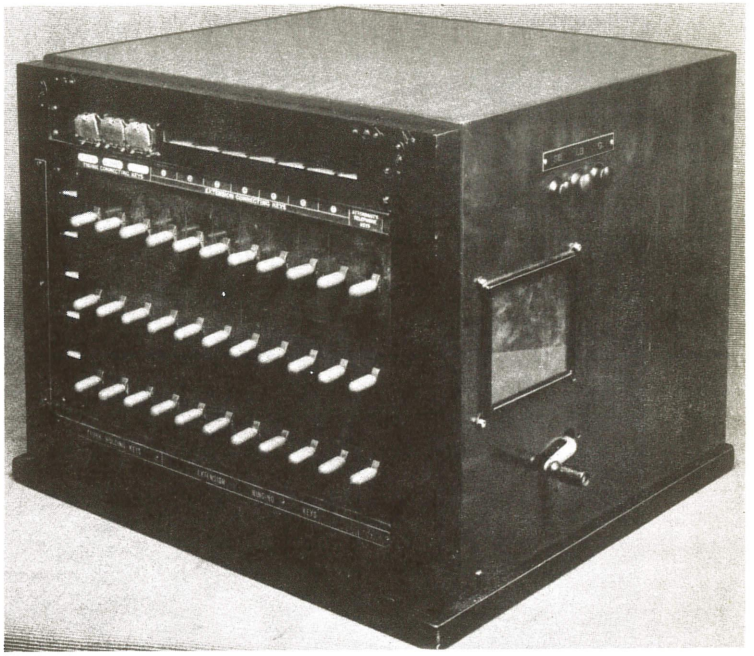


Figure 10-5 PBX Switchboard Serving Seven Extension Telephones Over Three PBX Lines. Provisions Are Also Made For Local Interconnection of The Extension Telephones.

The PBX situation brings additional problems. First, in the assignment of switching equipment to directory numbers, provisions must be allowed for the growth of a PBX service user's telephone requirements. This is illustrated by the non-assignment of jacks following the PBX groups as shown in Figure 10-4. "Holes" are thus created in the numbering scheme. This is, of course, of little importance in partially equipped central offices; but as an office grows, the reserve terminals of some PBX groups, of necessity, will have to be assigned. Later growth of groups, where insufficient or no reserve remains, necessitates directory number changes. The frequent reassignment of publicly established directory numbers is obviously not desirable from either the operating company or the subscriber's viewpoint.

Second, in consecutive number hunting the access and speed capabilities of the switching device may limit the size of the line groups.

Third, consecutive hunting, especially over large PBX groups having a high incoming traffic volume, causes a concentration of this traffic to be funneled into certain distributing paths and expansion stages as shown in Figure 10-7. This concentration may cause overloading of both the paths and the associated control circuits.

Non-Consecutive Grouping

The conditions outlined above are mitigated in present-day automatic switching systems by what is termed non-consecutive hunting. This may be illustrated by



Figure 10-6 Large PBX Switchboard Installation. This Switchboard is Equipped With Over a Hundred PBX Lines Serving Several Hundred Extension Telephones Which May be Connected to The Lines or Through The Switchboard to Each Other.

again referring to the manual switching of Figure 10-4. Let it be assumed that the lines following PBX group 0100 to 0103* have been assigned to other subscribers, and growth for this group in a consecutive manner is not practical. Note, however, that lines 0122 and 0123 are not assigned. If two additional lines are needed by PBX group 0100, lines 0122 and 0123 could be assigned, provided the operator is informed by distinctive marking that line 0103 is not the last line in the group but that 0122 and 0123 are included, 0123 being the last line. Hunting may thus proceed on this non-consecutive basis.

The lines to which the non-consecutive jump is made need not even be directory-numbered lines. In some automatic systems groups of unnumbered lines in addition to the ten thousand directory numbered lines are used for this purpose.

Night Service

Certain PBX lines in each group are usually used for night connections; that is, connected to extensions (branch telephones) at the PBX switchboard during the period when the board is unattended. For such purposes, a switching system must be

*These numbers represent only the last four digits of a complete telephone number such as ST 3-0100.

capable of providing access to some selected and specified lines of the PBX group on an individual basis as well as to the entire group when the normal procedure of calling the first line is used.

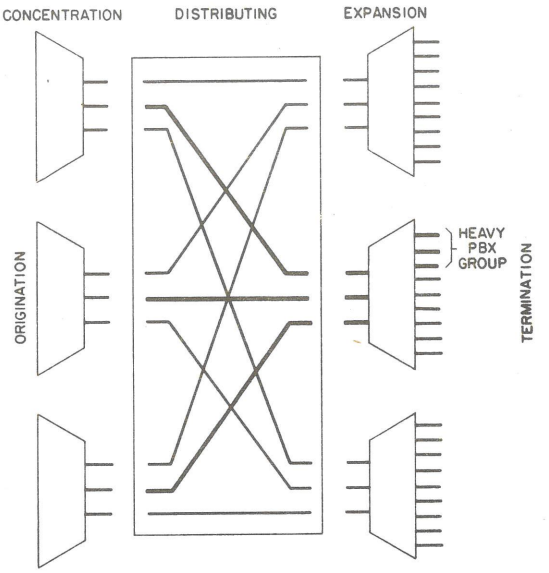


Figure 10-7 Concentration of Traffic Caused by Large Terminating PBX Group

10.4 SUBSCRIBER'S LINE CONSIDERATIONS—PARTY SERVICE

Two-Party Services

The decrease in cost of service, through the common usage of equipment as offered by party services makes available telephone communication to many people who cannot afford an individual line. Such common usage is provided by the connecting of a second telephone instrument to the basic line of Figure 10-1. This type of service is offered to subscribers in several forms as will be discussed.

Party line services, as any other added features to the basic line, increase the functions that must be provided in the switching system. For instance, identification of the calling subscriber must be effected for charging in the case of message-rate type of service. Also the proper bell on the line must be rung to signal the wanted subscriber on the party line. To illustrate the ringing operation on party-lines, consider the arrangement shown in Figure 10-8. Here the two telephone instruments of two different subscribers are connected to a single pair of conductors. Each telephone instrument has associated with it a bell connected to a different conductor. As one conductor of the line is called the "tip,*" the bell connected to this conductor is said to be on the "tip side" of the line and the party associated with the bell is identified as the "tip party." In a similar manner the other party is known as the "ring party**".

The assignment of directory numbers to party lines is accomplished in one of two ways: by the assignment of two different directory numbers such as 6903 and 8279 to the tip and ring parties respectively; or by the assignment of the same numerical value with an appended letter such as 3946J and 3946M. In either case ringing current must be applied to the tip of the line for ringing the tip party's

*The nomenclature, tip and ring, is derived from the parts of a plug used to connect subscribers' lines or other circuits manually. Wires connected to the tip, ring, or sleeve parts of these plugs are called tip, ring, or sleeve wires. These names have become standard for line circuits even where plugs are not used.

**This example and others to be given are not necessarily the only methods used in handling auxiliary features. They are, however, the most widely used at the present.

telephone, and to the ring side of the line for ringing the ring party's telephone. In non-translating switching systems, the dialing of different numbers such as 6903 and 8279 will cause the selection of two different line appearances. If these line appearances are connected together so that one appearance's tip is connected to the other appearance's ring, as shown on Figure 10-8, ringing current is directed to the proper party on the same line by the line appearance selected. This type of control involves a line appearance per party. Using the second method of differentiating, in which the appended letters distinguish between parties, the same line appearance will be selected upon dialing either 3946M or 3946J. The ringing function, however, is informed by the appended letter that ringing on the tip or on the ring of the line is required. In translating switching systems, either numbering scheme may be translated into a line appearance per line or a line appearance per party and ringing accomplished accordingly. It should be noted, however, that a separate directory number per party limits the total lines possible with the same central office designation to less than ten thousand. On the other hand, appended letters require the dialing of a fifth digit, for which the switching system must wait a specific time, even though this digit may not be required for the calling of a non-party line.

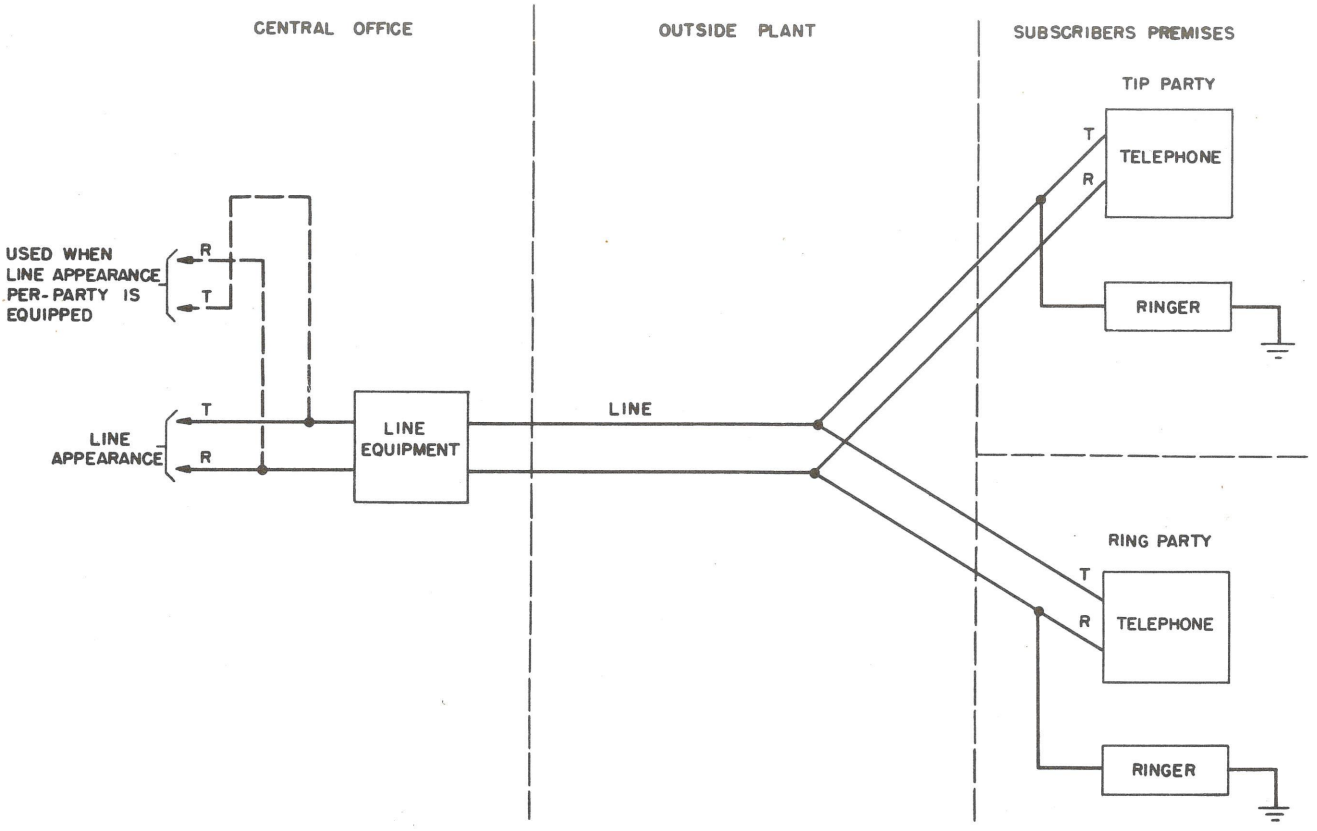


Figure 10-8 Two-Party Service—Ringing Considerations

Four- or More Party Lines

For four-party lines as shown in Figure 10-9, and ten-party lines as shown in Figure 10-10, the ringing problems are further complicated by the necessity of signalling one of four or more telephones on the line. Ringing on four-party lines may be accomplished by full selective ringing, semi-selective ringing, or coded ringing.

In full selective ringing only the wanted subscriber's bell is rung, while in semi-selective ringing, the wanted subscriber's bell plus a second subscriber's bell on the same side of the line is rung. The latter ringing signal, however, is coded, as shown in Figure 10-11, to designate only one party. Multi-party coded ringing (see Figure 10-10) consists of ringing all parties connected to one side

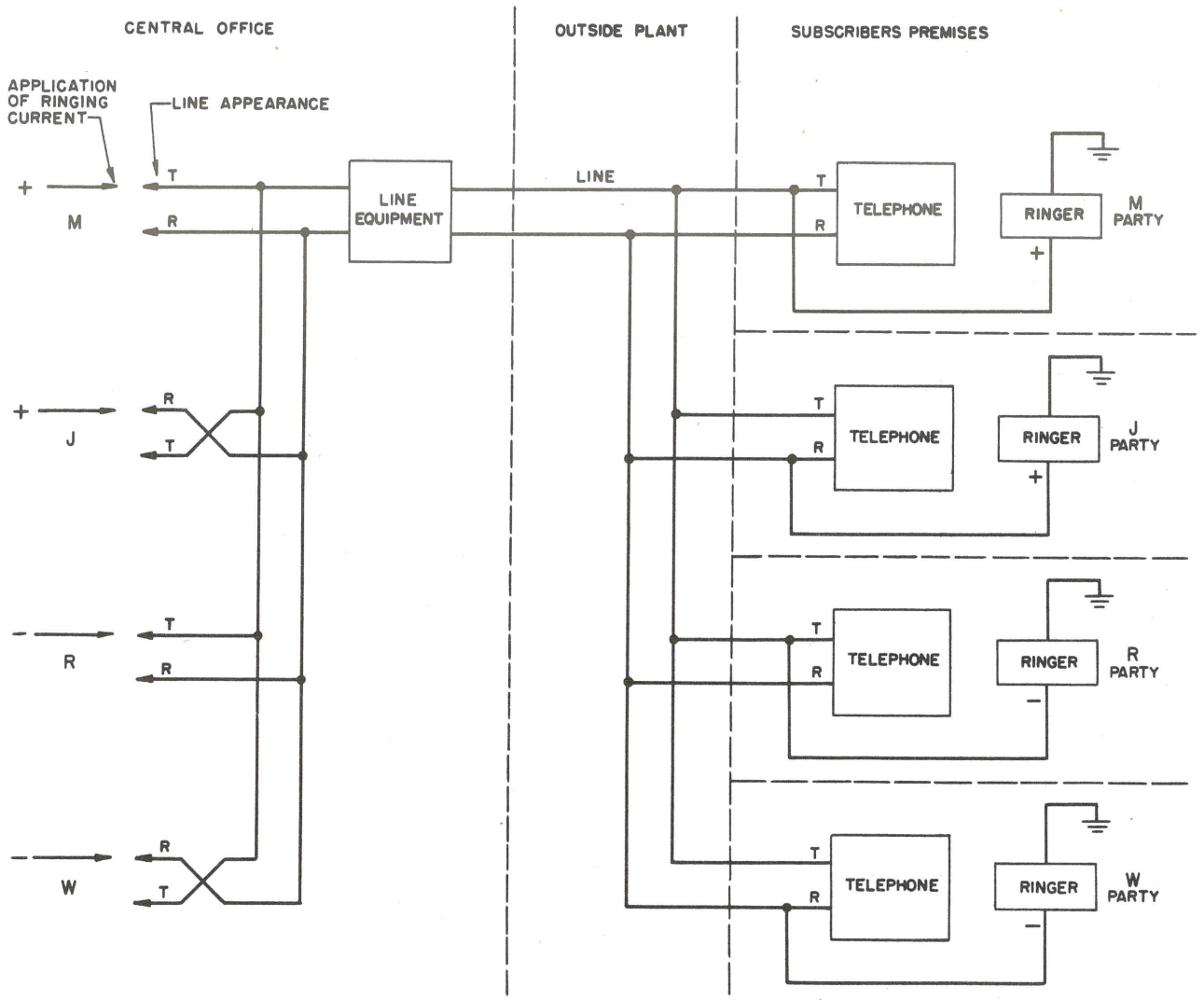


Figure 10-9 Four-Party Full Selective Ringing

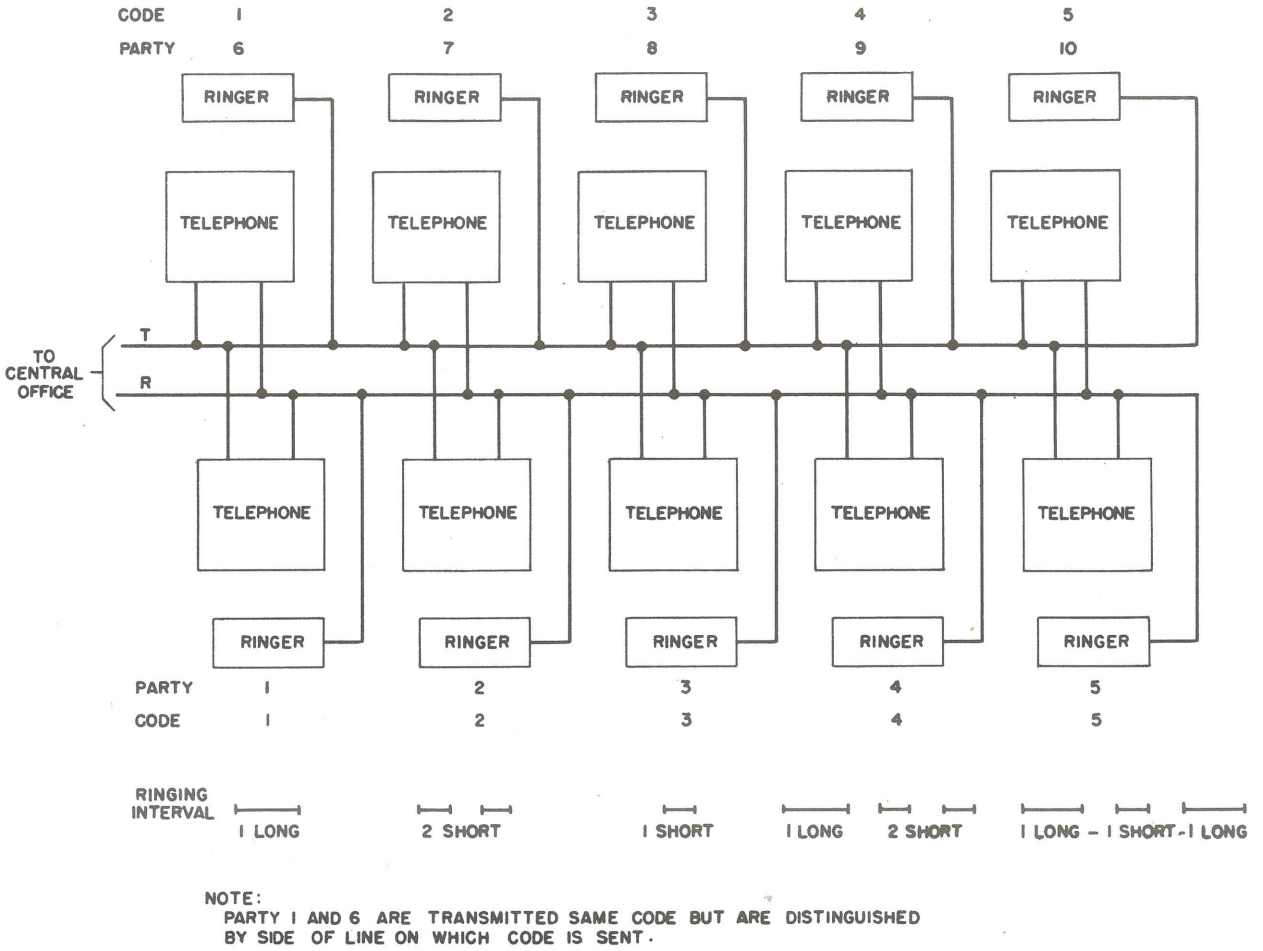


Figure 10-10 Ten-Party Line—Five Code. Note Party 1 And 6 Are Transmitted Same Code But Are Distinguished by Side of Line on Which Code is Sent

of the line by applying a distinctive code ringing designating one particular party. Either the four- or ten-party lines, as shown, may be handled on an appearance per line or appearance per party basis and the proper ringing signal supplied by the switching system.

Reverting Calls

An unusual problem is placed upon switching systems when a party-line subscriber wishes to call another party on the same line. At the time that the call is originated the line is made to test busy and thus the switching system would normally deny connection to any terminating call seeking it; furthermore, the busy condition is maintained for the duration of the originating call. The originating-terminating method of handling traffic would, therefore, prevent the setting up of a reverting call, that is, calls terminating to a party subscriber on the same line as the originating subscriber. Thus, the primary purpose of a switching system, the interconnection of any two subscribers, would at once be defeated.

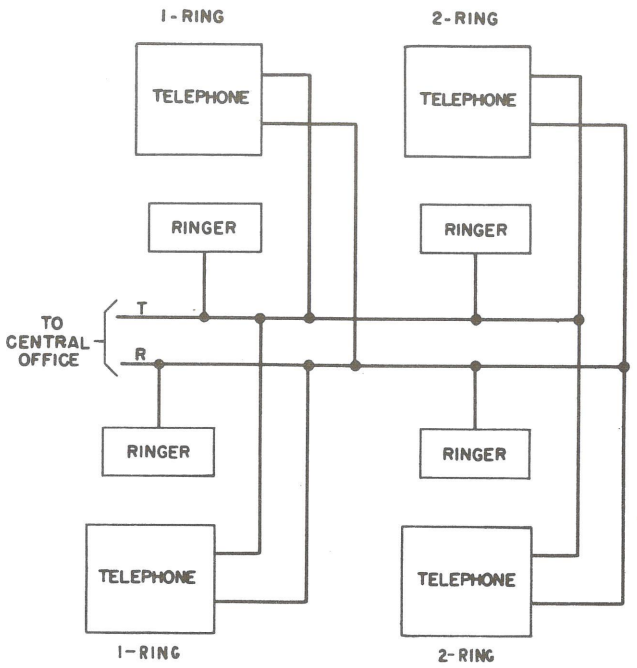


Figure 10-11 Four-Party Semi-Selective Ringing

Reverting calls are a necessary part of practical telephone service, when the office includes multi-party lines. Provisions for such calls must, therefore, be included as an adjunct to switching systems.

In general, the switching system, in setting up a reverting call, detects that the calling and called party are on the same line, cancels the busy test routine* and connects the line to a reverting call trunk. A distinctive tone is then returned the calling subscriber, informing him to hang up and clear the line for ringing. Both the calling and called party bells are rung, the calling party waiting for cessation of ringing as an indication that the called party has answered. Should the called party not answer, the calling party may trip the ring at any time by momentarily lifting the handset on his telephone.

10.5 SUBSCRIBER'S LINE CONSIDERATIONS—MISCELLANEOUS

Manual Lines

Certain subscribers may be incapable of operating the dial telephone because of a physical incapacity. In automatic switching systems it is necessary to serve originating calls from these telephones on a manual basis. Provisions for manual service must thus be made in automatic switching systems.

Such lines can be permanently and directly connected for originating purposes to answering jacks on the face of the Dial System "A" switchboard (to be described later) where calls may be handled by an operator (see Figure 10-12). Terminating calls to these manual lines are handled in the usual way by the automatic equipment. This over-all method however increases the cabling necessary to gain access to the answering jacks. In present practice, when a manual line in an automatic switching system originates a call, control circuits identify the line as a manual line, cancel dial tone and proceed to set up a connection to a trunk terminating in an answering jack on the DSA board. The DSA operator completes the

*The called party on the same line could never be busy if the calling party is able to originate a call.

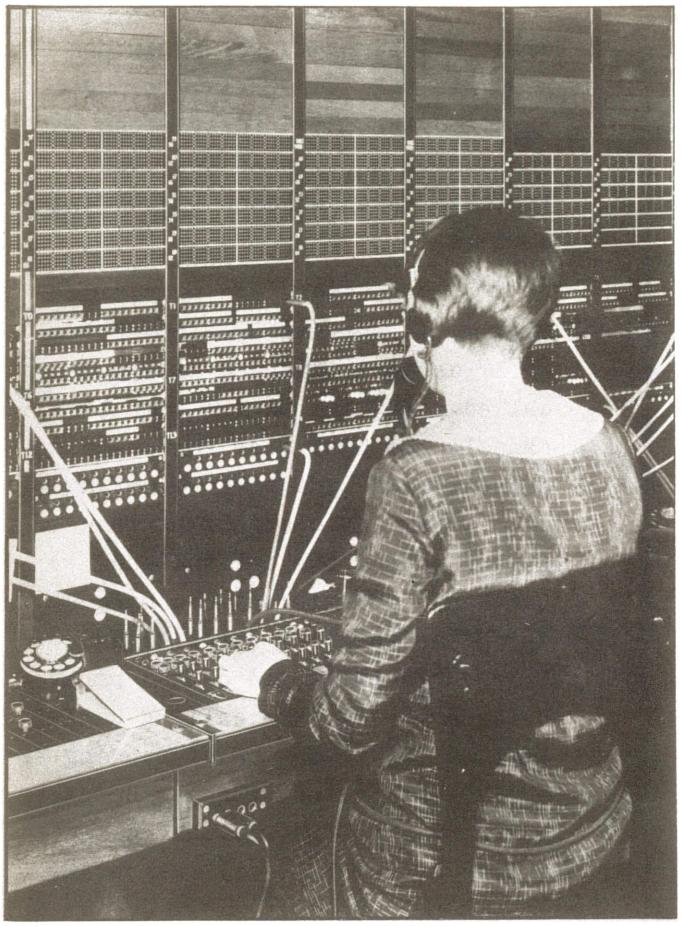


Figure 10-12 "O" Operator Position at Dial System "A" Board

call to the desired number at the request of the subscriber. Only a sufficient number of jacks to handle this type of traffic need be equipped; an answering jack per line is not necessary.

10.6 OPERATING CONSIDERATIONS

Subscriber Habits

The basic switching system functions were outlined in Chapter 3 on the tacit assumption that subscribers' behavior in originating or answering telephone calls and in the general usage of telephone facilities follows exactly specified procedures. In practice such ideal conditions do not obtain. A group of adjuncts, therefore, are necessary to guard against undesirable reactions in switching systems because of subscriber-error or interference. These adjuncts, however, do not generally take the form of separate circuits but appear as scattered additional requirements switching circuits have to meet. It is the purpose of this paragraph to list a few of the adjuncts falling in this category to gain an appreciation of their necessity.

In originating calls, subscribers every now and then commit dialing errors, other than dialing wrong numbers. The most common types of such errors are dialing before reception of dial tone, not dialing the entire directory number, waiting too long in between digits, "jiggling" the switchhook before dialing, dialing non-existant numbers, and so forth.

The first case may result in none or only a partial number of digits being registered in the dial pulse counting and registering circuit; the second case results in partial registration; the third case may have repercussions by holding up control units unduly long.

Switching system adjuncts to mitigate the effects of these errors take the form of timing circuits which require the entire directory number to be dialed in a predetermined time, or which limit allowance for the interdigital time between any two dialed digits to a fixed maximum value. These timing circuits initiate

both the release of apparatus held-up awaiting completion of dialing and the transmission of an informative tone to the subscriber as outlined under the section of disposition of calls in Chapter 9.

Switchhook jiggling before dialing causes momentary opening of the subscriber's line circuit which may be interpreted by the dial-pulse counting and registering circuit as the digit "one". Prevention of recording such "ones" before actual dialing starts is afforded by switching system adjuncts in the form of preliminary pulse absorbing arrangements which absorb these pulses, thereby preventing their storage. Non-mutilation of the subsequently dialed full directory number is thus safeguarded. This results in the restriction, however, that the digit one can not be used as the first digit of a directory number.

In the case of subscriber dialing of a non-existent number, the aimless "ringing out" on a vacant pair of terminals or the blockage of the call with no report to the subscriber of the condition encountered would be highly undesirable. Provisions for the connection of such calls to a source of vacant code or no-such-number tones are provided in modern switching systems.

10.7 TRAFFIC CONSIDERATIONS—TRAFFIC REGISTRATION

Switching systems are engineered on the basis of the demand for service at the time of installation plus the expected growth over a reasonable period of time. To indicate constantly change and growth trends, records of the usage of equipment, the denial of service because of all-circuits busy conditions, and so forth, must be actively kept. Necessary changes in facilities may then be handled with dispatch.

Registers on which the number of circuit usages, traffic overflow conditions, and the like, may be scored are designed into various circuits of switching systems. These registers form a group known as traffic registers. Such traffic registers and their control circuit are a necessary adjunct to switching systems in maintaining a high grade of service.

10.8 MAINTENANCE CONSIDERATIONS

General

Trouble conditions—due to wear, dirt, mechanical injury, and the like, inevitably develop to interfere with the functioning of telephone switching systems. Circuits to indicate and locate troubles are, therefore, necessary adjuncts to switching systems. In fact, in the design of complex automatic switching systems (Figure 10-13), the testing and maintenance features become a major consideration resulting in automatic routining, monitoring, trouble indicating, and trouble recording arrangements. In the present chapter these features are discussed only to create an appreciation of their existence and variety.



Figure 10-13 Section of Crossbar Type Switching System

Time Alarms

One of the most often recurring maintenance features in a switching system is the time alarm circuit which requires the completion of individual or collective switching operations within a predetermined time interval. If the required operations are not completed within the allotted intervals, visual and audible alarms inform the maintenance force of the occurrence and location of the trouble.

Checking and Self-Checking Circuits

Certain classes of troubles, mainly associated with the transmission of control or signaling information from one part of a switching system to another, may not result in blockage of the call but may guide it to an incorrect destination.

This type of trouble is exceedingly difficult to locate because of the number of circuits that become involved in establishing a connection. A need, therefore, arises for circuits which, during operation, check leads that are involved in the transmission of information for possible faults. Such circuits, known as checking circuits, give alarms when faults occur. Positive identification of the fault by the condition of the checking circuit provides definite location of the trouble.

Certain of the circuits conveying information may be designed as self-checking, that is possessing the ability to differentiate between false and true conditions passing over their lead and contact networks. These circuits will cause blockage of a call upon detection of a fault. Their inclusion in switching systems is necessary to insure the integrity of control and signaling information.

Trouble Indicators and Recorders

In manual switching, the attending operator can always attempt to by-pass, by the substitution of other circuits, the trouble conditions causing blockage of direct completion of a call. In other cases where troubles can be overridden, connections are completed in spite of the trouble. Reports, covering the troubles encountered are, of course, furnished to the maintenance forces.

In recent automatic switching systems control circuits are designed to closely simulate the manual operator's action upon encountering a trouble. These circuits, through a second-trial operation, explained elsewhere in this course, attempt to by-pass, by reselection, the paths on which a trouble is encountered, and to override some conditions which cannot be by-passed, but which will still permit interconnection and conversation.

In these systems, the trouble-reporting ability of the operator is also reproduced in the form of trouble indicating or recording equipment. Such equipment is called in by the control circuit experiencing a trouble condition, and a record is made of the conditions and switching components involved before a second trial is instituted. The record may be the lighting of certain labelled lamps associated with the trouble indicator or the punching of a card for permanent record by means of a trouble recorder (see Figure 10-14).

Routine Testing and Monitoring Circuits

Proper maintenance of switching systems entails the testing of individual and interrelated circuits either on a routine or service sampling basis.

Routine Test circuits are usually applied to specific circuits which do not have direct access to trouble indicating apparatus. Their application is essential (a) from a preventive maintenance standpoint for the detection of troubles before service interruptions; (b) from a trouble-shooting standpoint for locating troubles, and (c) as a means of ascertaining, that, after a trouble is cleared, the circuit is in working order. Routine test circuits for the purpose of (a) above are designed and may be manually set to test and progress from circuit to circuit, or for (b) and (c) to test an individual circuit any desired number of times.

CHAPTER 11

CHARGING AND BILLING FEATURES IN SWITCHING SYSTEMS

11.1 GENERAL

In considering methods of charging for telephone service, it is at once evident that billing may be based either on a periodic flat fixed amount, or on an amount determined by a measure of the actual service rendered. Charges, per instrument or line, in the flat-rate method of billing would depend upon the costs expended in operating the system, divided by the number of telephones and lines it serves. Charges, on the measured basis, are determined by each telephone's or line's share of the system costs as indicated by a metering of its originating traffic.

The information upon which charging and billing may be based can be gathered only at the time the processing of the call takes place within the switching system. For this reason, means for collecting billing data is one of the practical adjuncts to telephone switching systems.

It is the purpose of this chapter to discuss the problems imposed upon automatic switching systems by the methods and means involved in charging and billing. The problems and examples presented deal mainly with those encountered in present-day systems. The discussion is general, the main objective being to create an appreciation of the impact upon switching systems of such charging problems.

11.2 ZONING

From the standpoint of charging and billing, telephone service is divided into two general classifications: local and toll. Local service—if measured—is expressed in message units. Each toll message, on the other hand is rated directly in dollars and cents. Local service is based on a zoning system. This system establishes boundaries for flat-rate and one-message-unit zones and determines charge rates for calls between various zones in the local area. In some cases toll rates from the various zones to the same long-distance point may also vary. As an explanation, consider Figure 11-1. This figure represents a metropolitan area in which the densely populated business, industrial, and residential regions are at the center and designated as zones A, B, C, D, and E. These regions are shown enclosed by a heavy continuous line representing the boundary of the city exchange area. The city exchange area boundary may coincide with the political boundary of the city, or it may include certain closely associated suburbs, depending upon local conditions

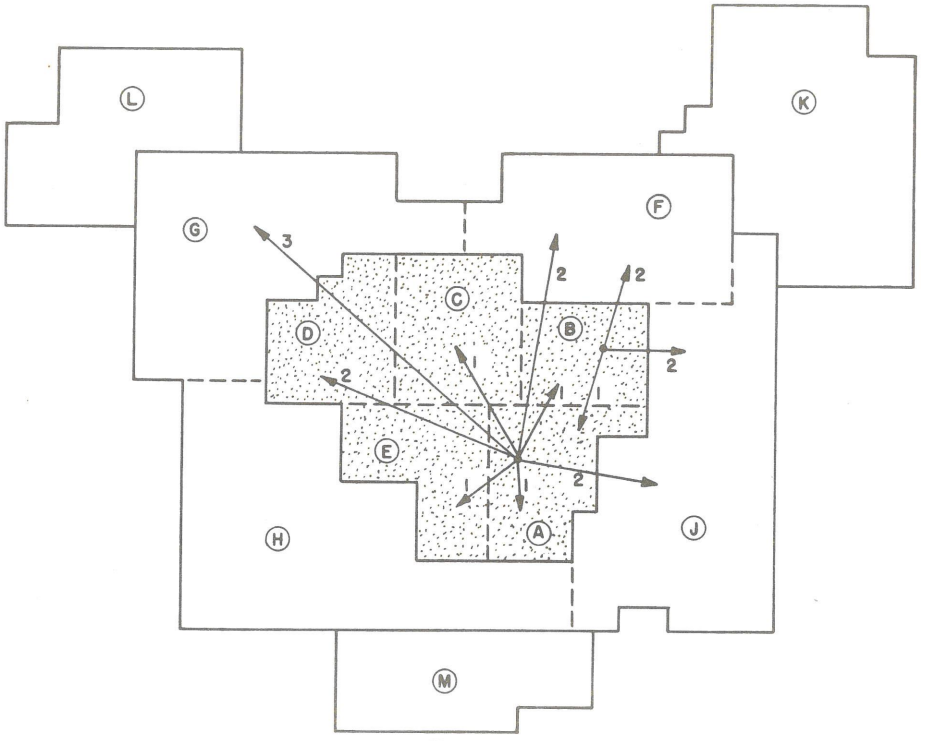


Figure 11-1 Zoning and Exchange Division in a Metropolitan Area

of distances and telephone plant growth. Surrounding the city exchange area are the inner suburban exchange areas designated F, G, H, and J. Adjacent to the inner suburban areas are outer suburban exchange areas, K, L, and M.

The city exchange area is divided into zones A, B, C, D, and E for the purpose of determining charge rates between various parts of the city and to the suburban areas. Arrows, radiating from zone A illustrate, in general, by the appended values the charge, in message-units, on calls from zone A to various other zones. Arrows radiating from zone B show by comparison the charging-rate variation between zones. The message-unit is the charge for a call originating and terminating in the same zone and lasting for a stated number of minutes.

The line of demarcation between local calls charged on a message-unit basis and toll calls charged on a mileage-time basis depends on local conditions. The outer suburban areas L, K, or M may, therefore, be handled on a message-unit charge or on a toll call charge basis. All calls beyond L, K, and M, however, will usually be on a toll basis.

11.3 FLAT RATE SERVICE

Flat-rate service is offered to subscriber groups, such as residential users of telephones, within which the situation and thus the resultant calling habits of the individual are closely the same.

In furnishing flat-rate service by automatic switching systems, where the flat-rate zone boundaries coincide with the area which may be reached by direct dialing, no special circuit features are required for charging purposes. Calls external to this zone must of course be directed to an operator. Where, however, the direct dialing scope exceeds the flat-rate zone as indicated in Figure 11-2, the problem of detecting all dialing attempts exceeding the flat-rate zone, if originated by flat-rate lines, and rejecting them, is at once presented.* The calling subscriber is then either required to dial or is automatically routed to the "O" operator who will complete the call and make the proper records for charging purposes. Thus, subscribers in zones A, B, C, and E may complete calls within these zones by direct dialing, but calls to D, F, G, H, or J must pass through an operator. This operator tickets the call by completing the form shown in Figure 11-3 from information gained from (a) the calling subscriber, (b) from the answering time of the called telephone, and (c) from the release time of the connection.

Completed tickets are forwarded to the accounting department where they are computed in money value and filed for billing purposes. The flat-rate subscriber's periodic bill, thus, consists of the flat-rate charge plus a tabulation of the ticketed calls.

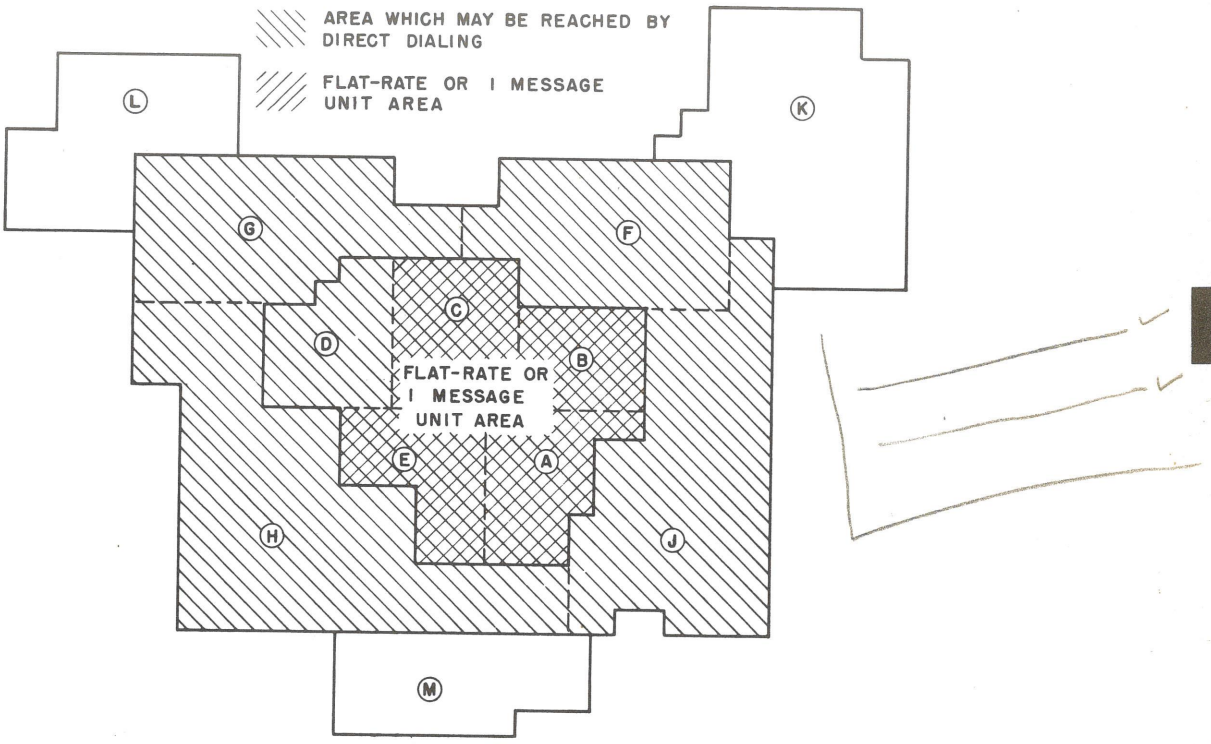


Figure 11-2 Direct Dial Zone Exceeding One Message Unit Zone (A to H Included in Direct Dialing Zone—Based on Figure 11-1)

*This subject of rejection is fully covered under paragraph 11-4.

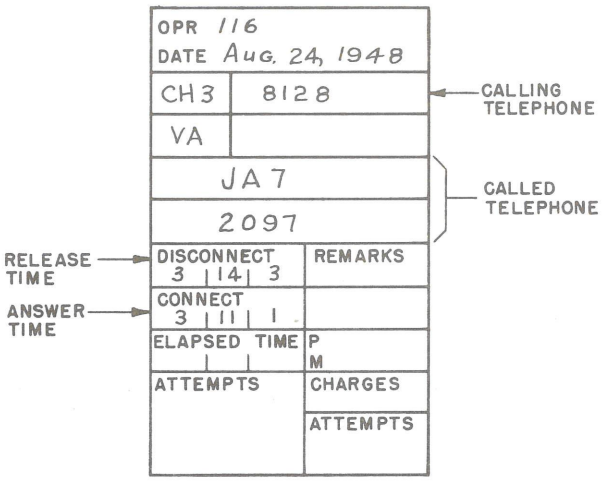


Figure 11-3 Operator's Ticket—Local Area

11.4 MESSAGE-RATE SERVICE

Message-Rate Service, as a class of service distinction, indicates the charging for local calls on a metered basis. Toll calls which are billed, in any class of service, on a measured basis are not included. A simple metering device (Figure 11-4) upon which completed local calls may be scored is thus indicated for use. This device, the message register, was introduced in Chapter 10.

Message rate service requires the automatic switching system to perform certain functions of charging which are not necessary in serving flat-rate lines exclusively. These functions relate to identification of the subscriber's line for the purpose first, of ascertaining that line's right to originate by direct dialing the call described by the dialed office code, and to detect the presence and type of charging apparatus associated with the line; second, of determining that the call is a chargeable call; and third, of setting up the proper equipment and procedure for actuating the charging apparatus.

In practice, subscribers' class-of-service identification is accomplished in one of two ways: indirectly as a result of segregation of each class to a different equipment group, or directly by means of class information signal leads. In the first case the group is limited in access to only those connecting circuits employing equipment to accommodate that class of service. In the second, information signal leads are employed to inform the control circuits of the subscriber's class. The control circuit will respond, through the information received, to direct connection only through equipment applicable to that class.

The subscriber's right to originate the call to the dialed office code, through direct dialing, is determined automatically by a comparison of the class-of-service information and the office code. Such cases, for instance, as a flat-rate line originating a two-message unit call will cause the control equipment, through the non-agreement of the class-of-service indication and the zone identity of the office code, to reject the call by routing it to a "O" operator or by returning a vacant code tone. This use of class information leads to greater complexity as the number of specific classes of subscriber lines and the possible dialed routings increase.

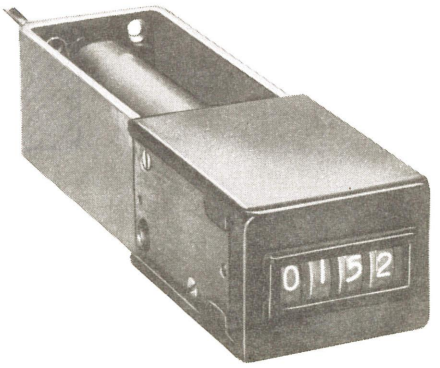


Figure 11-4 Message Register

The classes of service involved in charging control are flat-rate lines, individual message-rate lines, two-party message-rate lines, and coin lines. Flat-rate lines are included because for them the charging operation must be cancelled in processing originating calls. Individual lines require a simple operation of scoring or non-scoring on a single message register, while two-party lines require a more complex operation. Here one of two message registers on the same line must be selected for scoring purposes. Coin lines are a special form of message-rate lines on which charging, and direct collecting from the user is performed. Collecting or returning of deposited coins must therefore be accomplished.

The charging control equipment is generally placed in a trunk or its equivalent. This equipment, in the case of message register control (coin control will be explained later), is set for charging or operating the message register only upon determination that the call is a chargeable call. This determination is made jointly by the switching control function in ascertaining that the call is not to a free code, and by the supervisory function in verifying an answer condition of the called line.

Free codes are usually single-digit codes such as "0" for assistance operator, or three-digit codes such as X11 (X = any digit 0 to 9) to information centers, long distance operators, and repair centers. Certain seven-digit codes such as OFficial 3-9000 to telephone company business offices also cause a no-charge setting of the charging equipment.

The answer condition is based upon a positive signal that the called subscriber has answered his telephone and interconnection is completed. This signal is the operation of the called subscriber's switchhook. Busy or overflow conditions reached by the calling subscriber will therefore not cause a charge condition to be set up.

In some localities modification of the message unit charging equipment is necessary for overtime charging on calls within the one-message-unit area. Here timing circuits are introduced into the charging equipment for the purpose of timing the duration of the interconnection. At the termination of the initial period, usually five minutes, and at the termination of each overtime period of a certain duration, the message-register is caused to reoperate.

As shown on Figure 11-2, external to the one-message-unit area are the zones requiring a greater charge. Calls to these zones bring additional problems for the switching systems.

Again, if the direct dialing area coincides with the one-message-unit area, calls to the external zones, which the automatic system cannot directly reach, must be directed to an operator for completion. If, however, the direct dialing scope of a metered telephone exceeds the one-message-unit area, as shown in Figure 11-2, two methods of completing calls are available. One, as has been described under flat-rate service, is to reject all calls terminating beyond the one-message-unit area unless placed through an operator. The other, known as zone registration, allows such calls to be completed by direct dialing, scoring charges by operating

and reoperating the message register as many times as required by the zone charge. As an example, the message register associated with a telephone in zone A, Figure 11-1, would be operated twice on a call to zone D, or three times on a call to zone B.

The first method relieves the switching system of any equipment for a determination of rates. It, however, interposes an operator and a manual operation which increases the time of establishing the call. The second method provides complete automatic establishing of the connection and produces bulk billing, that is, it sums the multi-unit calls into a total number of message-units which cannot be segregated from single message-unit calls for billing purposes.

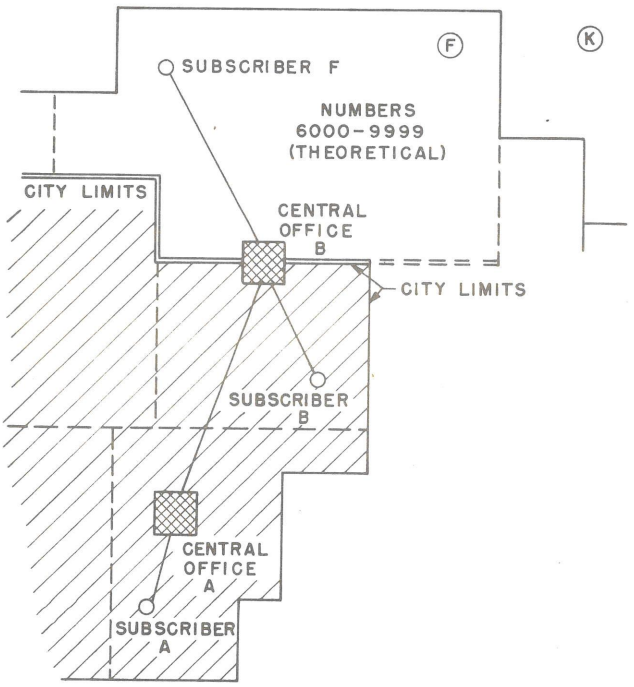


Figure 11-5 Physical and Theoretical Numbers

With zone registration, the switching system must determine either from the dialed code or from unique characteristics of the trunk to the called point that (a) zone registration is necessary, and (b) the message register of the calling line must be scored X number of times. Usually, overtime registration is included in zone-registration.

The occasional need for unusual charging controls in zone charging territories where direct dialing beyond the one-message-unit zone is possible may be brought about by the arrangements of telephone plant. For example, consider the situation where because of the present number of telephones installed, the expected future growth of service and the desirability of centralizing automatic switching equipment, as discussed in Chapter 1, one central office unit of a maximum 10,000-line capacity is sufficient to serve two zones. This situation is illustrated in Figure 11-5 which is a section of Figure 11-2 covering zones A, B, C, and F. Here central office B serves both zone B and zone F.

Under these conditions, a call may be directly dialed by a subscriber A in zone A through central offices A and B to either subscriber F in zone F or to subscriber B in zone B. As previously discussed, however, a call from A to F is worth three message-units. As subscriber B or F is reached by dialing the same central office code (being in the same office) some means of distinguishing between them, or more properly between the zones in which they are located, must be undertaken for charging purposes.

A solution to this problem, applicable to systems in which a form of common control directs both the originating and terminating end of the connection, was introduced in Chapter 8 under Theoretical Numbers. With this method all directory numbers in zone B are prefixed with a distinctive office code, such as, CIty-2 and all numbers in zone F by say, SUburban-3. These two codes when dialed by subscriber A in zone A will direct the selection of the same paths and trunks to office B but will indicate to charging equipment in office A a one-message-unit value for CIty-2 and three-message-units for SUburban-3. Arbitrarily, CIty-2 may be said to indicate a physical series of telephone numbers while SUburban-3 indicates a theoretical set of numbers.

With this method, however, it would be possible for zone A subscribers to reach subscribers in zone F by dialing the one-message-unit CIty-2 code which routes the connection to office B trunks. To prevent such action all telephones in zone F may be assigned directory numbers in an arbitrary series, for example, between 6000 and 9999. These numbers are then identified by the terminating control equipment as belonging to the theoretical group, and may be completed to only under direction of the theoretical office code prefixing the directory number. The numbers are then said to be discriminating.

In setting up an interconnection the switching system in office A passes to office B along with the directory number an indication that a physical or a theoretical office code was dialed. If, in the terminating control equipment, the directory number and the physical-theoretical indications agree, the call is completed. If disagreement is detected, the call is routed to an intercept operator.



Figure 11-6 Coin Telephone

11.5 COIN-BOX SERVICE

Coin-box service, as previously stated, is a form of message-rate service in which telephone service is paid for in cash by the customer at the time of processing his call.

The coin telephone (Figure 11-6) will accept nickels, dimes, and quarters in separate slots. After a coin is deposited it passes through a chute which causes it to strike a gong whose tone indicates the value of the coin. The coin then falls into a hopper where it trips a trigger arrangement which causes circuit closure of one side of the line to ground through a high value of resistance as a means of indicating its presence. The trigger, when once tripped, cannot reset unless the coin is collected or returned. The coin finally comes to rest upon a

platform which may be tilted one way by a coin magnet to collect the coin, or the opposite way to deliver the coin to the return slot. The alerting of the central office equipment is caused either by the lifting of the handset from the switchhook or by a combination of the switchhook action and the coin ground, depending upon whether coin-first or dial-tone-first service is being rendered.

When dial-tone-first service is provided, the user may start all calls and complete free office-code calls without depositing a coin. With coin-first service a coin must be deposited to start all calls. The coin will be returned to the user on free office-code calls and collected on chargeable calls. In either case the coin will be returned on busy or overflow conditions.

Coin-box service imposes charging problems upon the switching system which are similar to those of message register operation. To repeat, these are: class-of-service identification for the purpose of allotment of charge control equipment; differentiation between values of chargeable calls; and certification of an answer condition. In addition to these, problems of detecting the presence of a coin in the coin device and returning of the coin under certain conditions is also presented.

Present coin-box service operation, through class-of-service identification and interpretation of office code dialed, allows direct dialing of all local calls in the one-message-unit zone. Coin control apparatus, in the central office, is capable of detecting the coin ground on the line indicating the presence of a coin, and collecting or returning the coin as the case may be.

If the territory being served incorporates overtime charging, a charge is made for the initial period of say five minutes and for each overtime period. The intervals are measured by a timing device which is usually associated with the trunk equipped for coin control. In this procedure the coin is collected approximately 4-1/2 minutes after the answer condition. Concurrently, a tone is placed on the connection for a half-second to signal that a second coin must be deposited. At the end of five minutes, if the connection has not been released, the coin control circuit again tests for presence of a coin. If no additional coin has been deposited, the connection is routed to an operator.

Attempts to dial beyond the one-message-unit zone where the automatic switching system boundary coincides with this zone, of course, routes the connection to a vacant code tone. Where, however, the dialing scope exceeds the one-message-unit zone, two procedures are available. One of these, used in many localities, is the rejection of direct dialing and the subsequent routing of the call to "intercept" or to "O" operators. The other, installed in certain large metropolitan areas, allows direct dialing to two-and-three-message-unit zones through the application of zone dialing trunks. In those cases, with the aid of class-of-service identification and interpretation of the dialed code, a parallel connection is routed for coin control to an operator, along with a signal light indicating the charge value. The direct connection is held blocked until approved by the operator.

Both of the above operational routines interpose an operator for the purpose of charging and collecting. As has been stated, the coin device is limited in that it indicates to the switching system only the presence of a coin and not the number of coins or the value of each. This is the function of the operator. It may be said at this point that the design and construction of equipment which would perform a coin counting function and inform the switching system of the amount

deposited is not an impossible task. Similarly, coin control circuits could also be designed which would be capable of verifying the deposits, and check them against the value, in message-units or monetary divisions, of the dialed code. Problems, however, in the application of such circuits are formidable.

In the first case mentioned above where direct dialing beyond the one-message-unit zone is rejected, the "O" or other operator receives a verbal order from the user for the called number, determines the charges necessary, returns the initial deposited coin (the value of which she does not know), instructs the user to deposit the required amount, verifies the deposited amount, then completes the connection. Verification of the deposited amount is accomplished through the reception of tones caused by the coins striking gongs on their downward fall through the chute. The tones are distinctive, usually consisting of one high pitched tone for a nickel, two high pitched tones for a dime, and one low pitched tone for a quarter. The trunks employed in this procedure are usually arranged for automatic collection and manual return. On "don't—answers," busy, or overflow conditions the operator will return the coin.

The use of zone dialing trunks lightens the load upon the operator. Here the operator need merely return the initial amount, request deposit of the amount indicated, verify the deposit, and signal the control circuit to proceed. This last act automatically removes her from the connection. Collection or return of the deposited coins is then automatic with the trunk.

Overtime charging results from timing of the connection directly by the operator in the first case, and the automatic resignalling and connection of an operator in the second case.

11.6 CHARGING FOR LONG-DISTANCE TELEPHONE SERVICE

The charge of a long-distance call is directly dependent upon the distance covered, the time duration of the call, the time of day when the call is placed, and the type of service requested.

Long-distance telephone calls, at the present, are completed through one or more long-distance operators. As may be seen from the arrangements shown in Figure 11-7, operators may complete the call by means of dialing, where automatic toll switching systems are available, or by manual methods where manual toll switching systems are employed. The toll outward operator has, in any of the arrangements shown, direct contact with the calling subscriber and the outward portion of the call. For this reason all necessary information for charging the call to the originating telephone is available to the outward operator, who records this information on the ticket shown in Figure 11-8.

11.7 AUTOMATIC TICKETING

Under the discussion of flat-rate and message-rate services, it was pointed out that direct dialing of calls within an automatic switching exchange may be limited by the necessity of introducing an operator for charging purposes. Automatic ticketing however, which will allow direct dialing of calls that were formerly denied because of charging limitations, has recently been introduced. In this system the operator's function of gathering and recording charging information is replaced by automatic circuits. This added equipment prepares an individual printed ticket showing the information needed for charging for each call.

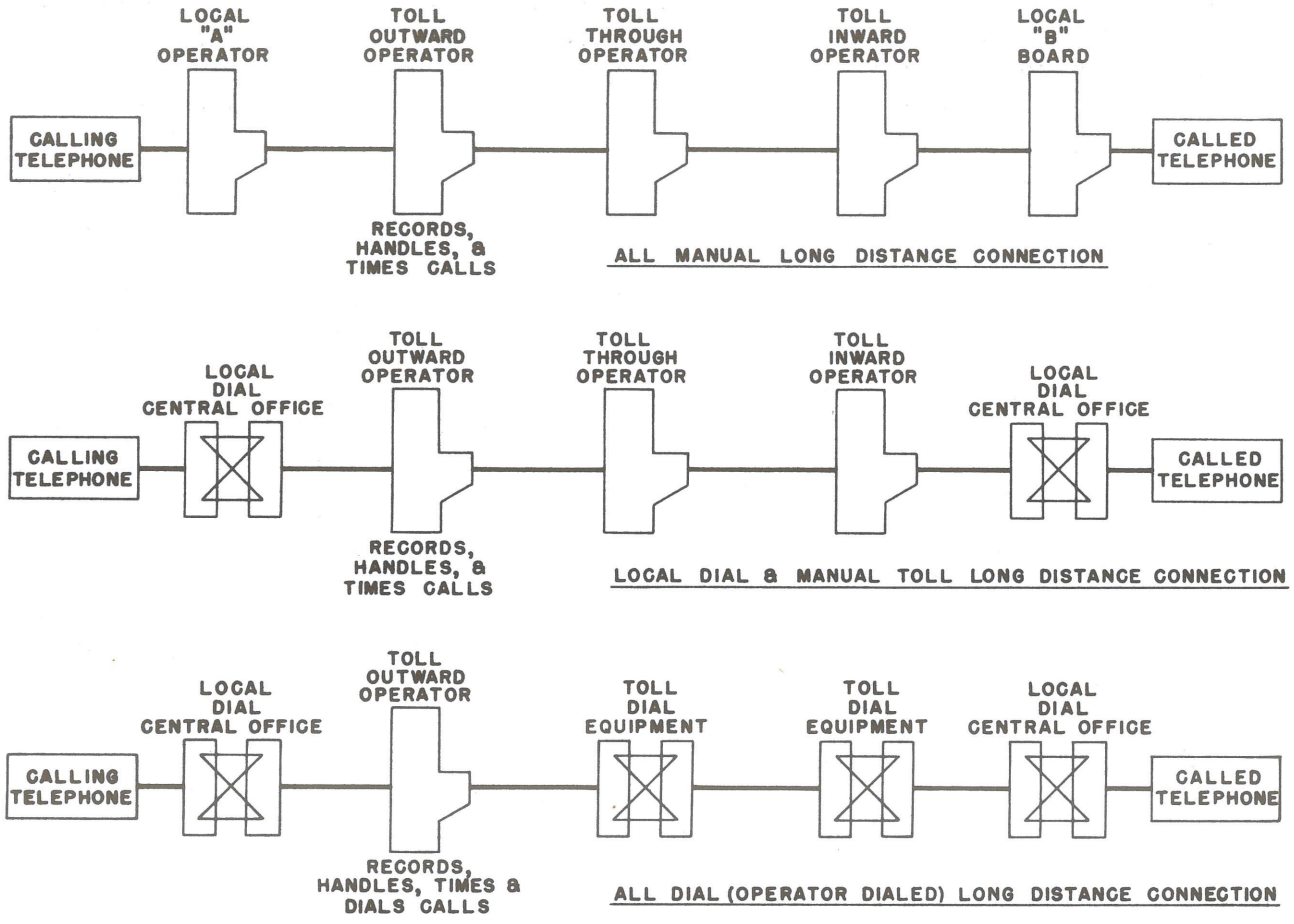


Figure 11-7 Charging on Toll Calls

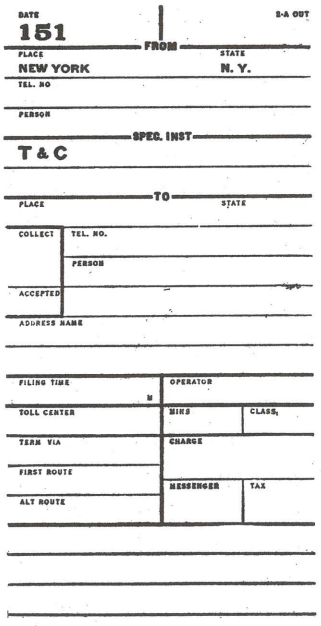
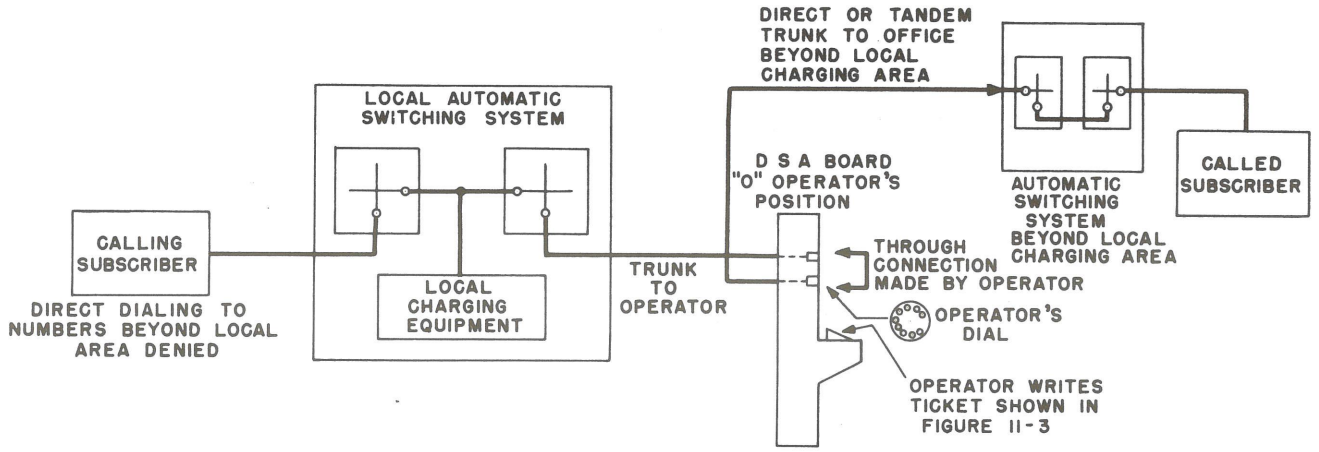


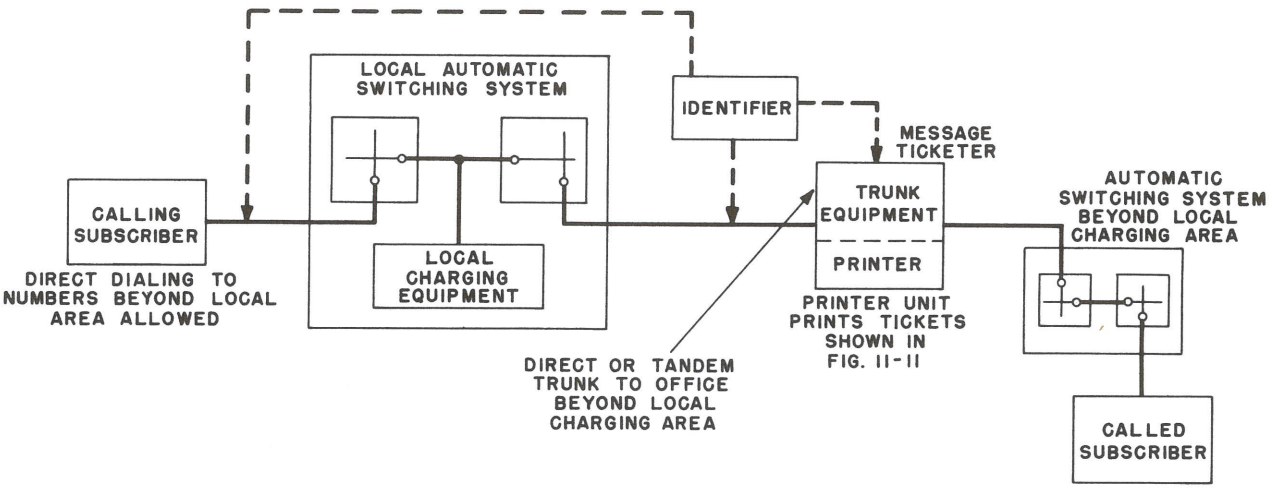
Figure 11-8 Outward Toll Ticket

Figure 11-9 illustrates the arrangements involved in applying automatic ticketing to calls beyond the one-message-unit area, and compares this method of ticketing with "0" operator ticketing. It will be noted that the tandem or direct trunks to points beyond the one-message-unit area are removed from the D.S.A. board and made directly accessible to the local switching equipment. This allows, from the switching system standpoint, direct dialing of these trunks and the selections beyond.

Associated with each trunk, so used, is a message ticketer (Figure 11-10) which prints, for each call served by the trunk, a ticket in the form shown in Figure 11-11. An identifier, to which the control circuits and trunks have access,



A INTERPOSING OPERATOR FOR CHARGING PURPOSES



B INTERPOSING AUTOMATIC TICKETING ON DIRECT DIALING FACILITIES

Figure 11-9 Interposing Automatic Ticketing on Direct Dialing Facilities

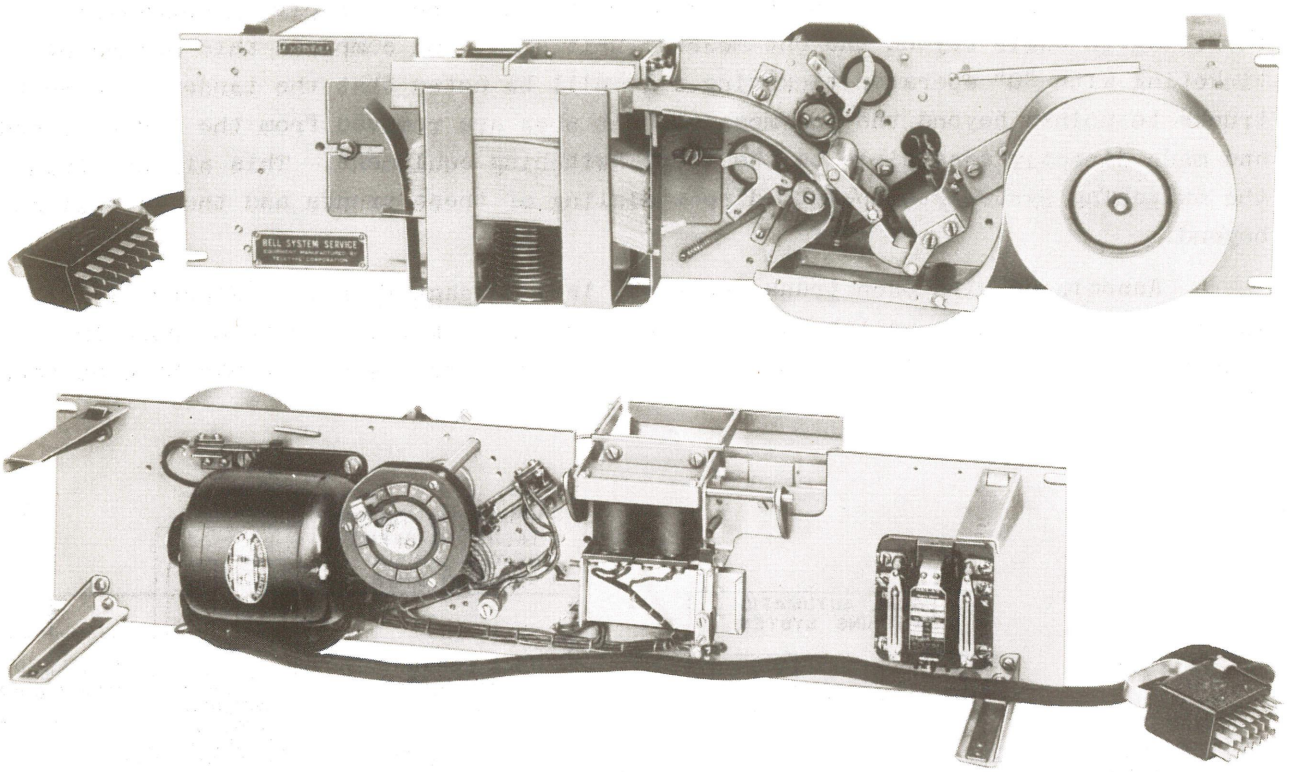


Figure 11-10 Message Ticketer

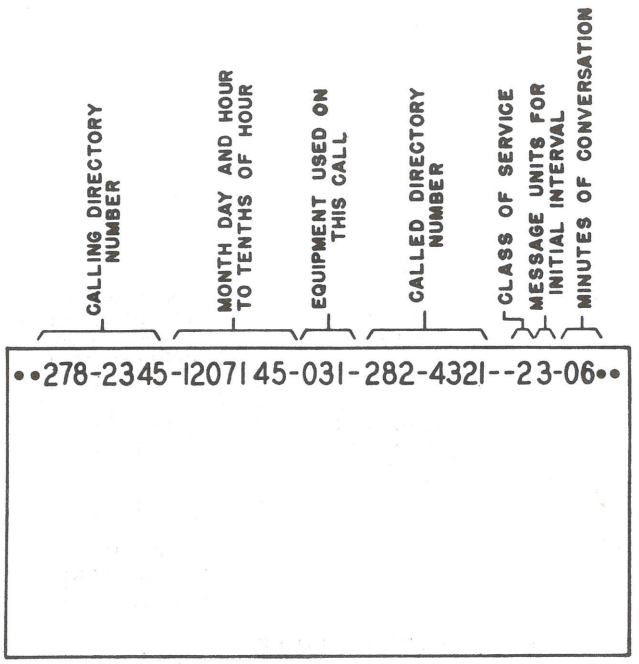


Figure 11-11 Ticket Prepared by Automatic Ticketing Equipment

aids in the gathering of the charging information and controls the printing of the initial entries. Timing of the connection is accomplished in the message ticketer trunk.

11.8 AUTOMATIC MESSAGE ACCOUNTING

The previous paragraphs have dealt mainly with the gathering and recording, in the central office, of the charging information necessary to prepare billing of the subscribers for services rendered. This information, as has been seen, was recorded through various methods involving manual, semi-manual, and fully automatic procedures. The direct product of these operations are the local tickets (Figure 11-3), the

message-register readings, the long-distance or toll ticket (Figure 11-8), and the automatically printed ticket (Figure 11-11). These different types of tickets and records furnish the accounting departments of the operating companies the information necessary for preparing local service statements covering bulk billed calls and toll service statements covering detail billed toll calls.

The accounting department starts with the central office record of completed calls, prices each toll call, sorts the priced toll calls by calling telephone number, and prepares the subscribers' bills. All this is, at present, on a manual basis with such aids as sorting racks, and the usual commercial office machines.

The pricing, sorting, and summarizing of the thousands of tickets that are originated each day is a costly process. Also the work is of a repetitious nature. Checks and rechecks at several stages of the billing process are necessary to insure extreme accuracy of the results.

Automatic ticketing has introduced the possibility of collecting in the switching center the charging information on an automatic basis. The extension of automatic operation to the accounting and billing processes is a logical step towards more efficient over-all measuring of and billing for telephone service.

A system, designed to provide automatic recording and processing of charging information, known as Automatic Message Accounting System or AMA is now in existence. This system is divided into two main parts, the AMA central office recorder and the AMA accounting center.

The AMA central office recorder makes permanent record of all billable calls, dialed by subscribers, on a continuous paper tape. For toll calls, on which detailed billing is required, this includes the calling telephone number; the called telephone number, office, and area; billing index or class of call; transmission equipment number for call identification purposes; and answer as well as disconnect times. The called number, office, and area are omitted from bulk billed calls. These items of information are recorded on the tape as they become available. Initial information as to the called and calling number, the transmission equipment identification number, and billing index are first recorded with the completion of dialing. Later, when the call is answered, an answer time entry containing the transmission equipment number and the time of answer is made. In the same way a disconnect entry containing disconnect time and transmission equipment number is made at the termination of the call. These entries are separated from each other by corresponding fragmentary entries of other calls, because the AMA recorder is common to a large number (100) of transmission circuits. The application of AMA recording to a particular switching system is shown in block diagram on Figure 11-12.

Figure 11-13 shows the AMA accounting center in block diagram. The tape from the switching center is fed into the assembler where the fragmentary entries of each call are brought together. In the computer chargeable time for detail billed calls and message unit values for bulk billed calls are determined. The calls are then sorted by calling telephone numbers in the sorter, the bulk billed

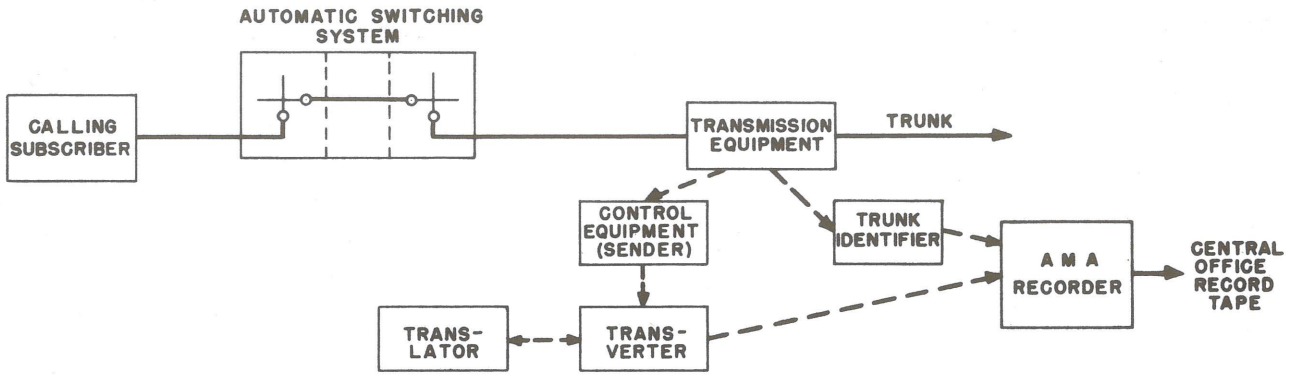


Figure 11-12 A.M.A. Recording

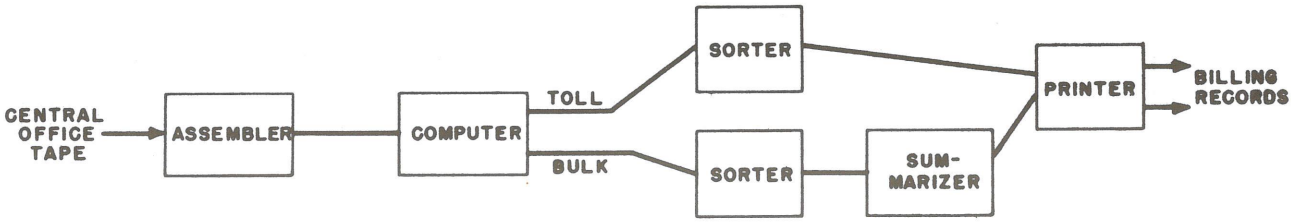


Figure 11-13 A.M.A. Accounting

calls are summarized in the summarizer, and the entire record is printed in the printer in the form of toll slips and message-unit summaries. At the present time some manual work still remains in the preparation of subscribers' bills.

11.9 CONCLUSION

Charging subscribers for telephone service is not a simple "over-the-counter" transaction in which a fixed payment is received for a ready-made product. Telephone calls are individually "tailor-made" to fit the requirements of the calling subscriber. Charges, therefore, must be based in general upon the individual call, taking into account duration and distance. The automatic collection of coins and the required call-data, and the evaluation of the great bulk of message-unit calls is a very substantial practical adjunct of switching systems.

CHAPTER 12

ENGINEERING ASPECTS OF SWITCHING SYSTEMS

12.1 INTRODUCTION

The preceding chapters have discussed the basic principles of telephone switching and many of the facilities that it has been found necessary to provide in switching systems in addition to the fundamental interconnecting and control means. Although no specific systems have been described or named except in passing, the primary functions that must be performed by any telephone switching office have been presented. Furthermore, the concepts underlying the various types of switching systems that fall in the broad categories of progressive and common control have been developed.

Although this functional approach is sound for developing an understanding of the nature of telephone switching, it does not include a very important design aspect of the over-all problem—the flexibility that must be incorporated in telephone switching systems so that these can be engineered to satisfy specific sets of conditions. Since these conditions vary tremendously from one locality to the next, an installed central office must, to a large extent, be "hand-tailored" or "traffic engineered" to suit the requirements of the particular area which it serves, in order to give good service at an economical cost. As an illustration of of the profound effect which this factor has upon system design, the present chapter will discuss the engineering of a local central office to meet a given set of conditions. It should be kept in mind that this example has the sole purpose of indicating the impact of traffic engineering factors upon design; the general subject of traffic engineering is so great in content and importance that an adequate exposition requires separate treatment.

The variation in conditions which central offices must meet arises from two major causes. One of these concerns the subscribers themselves, taken as individuals and in groups which are served by particular offices. The other has to do with the existing telephone plant into which a central office must fit.

The most obvious difference to be found among subscriber groups is size. In isolated rural districts the number of subscribers that must be served by a single central office may be well under one hundred. At the other extreme, in densely populated metropolitan areas, the concentration of subscribers may be so great as to require several immediately contiguous 10,000-line offices. Between these extremes all gradations in size occur. Central offices must be designed, therefore, to accommodate any number of subscribers up to some more or less arbitrary

limit without too great a variation in efficiency. The approximate upper limit for a single office is 10,000 line numbers, although in some cases it is economical to group two or more such office units and permit them to use certain equipment in common.

The telephone traffic presented by different groups of subscribers also varies widely. Residential type traffic is generally characterized by a relatively low calling rate per subscriber, accompanied by a relatively long average holding time per call. With business traffic, on the other hand, the calling rate is more often high and holding time low. Central offices must be designed to handle either type of traffic or a mixture of both. Furthermore, within a particular group of subscribers, the individual variation is usually greater than is found among groups.

In addition to these factors, the types of service expected by groups of subscribers cover a wide range. In smaller towns or rural areas the emphasis is on straightforward telephone interconnection based on a simple rate structure. Economic conditions may dictate extensive use of multiparty lines. In metropolitan areas requirements are more complex, so that central offices must provide for dozens of different classes of service, widespread provision for PBX lines, and a great many specialized auxiliary features. It is unusual for any of these conditions to remain static during the lifetime of an office. Population and demand for telephone service may increase or decline in a given area. Residential areas may become industrial or business centers with the passage of time. System design must be such that if these changes are anticipated by traffic engineers, central offices can be conveniently engineered for future growth and change.

Associated with these traffic aspects of switching design are the variety of numbering plans that the operating telephone companies may require. Flexibility in accommodating any combination of these must be designed into each new system to meet field conditions.

Existing telephone plant has considerable effect upon the design of switching systems, since a new central office must be capable of fitting into almost any conceivable combination of older plant. Advances and improvements in manual and automatic switching systems have been characterized as much by changes in interoffice signaling techniques as in internal switching methods. Since it is usually uneconomical to replace existing switching offices or even to change them radically to function with a newly installed office of later design, each new system must be designed for intercommunication with older types. A good example of this is furnished by the current No. 5 Crossbar System which utilizes multifrequency signaling for information transmission in connection with other No. 5 offices. However, the design also includes incoming registers and outgoing senders equipped for dial pulsing, revertive pulsing, and P.C.I. pulsing so that the system can function with existing manual, step-by-step, panel, and No. 1 Crossbar offices. Although designing on this basis tends to perpetuate obsolete methods, at the present time it is an economic necessity.

Since field conditions do vary over such a wide range and switching systems are designed to provide for meeting such conditions, each new central office is a unique engineering problem. This is not to intimate that the basic systems and circuits are not standardized. Rather the implication is that from the very inception of system design one of the major requirements is to make provision for flexibility in equipment quantities and optional features. If this design objective is met, it becomes possible to engineer a central office with considerable precision to provide good service at a reasonable cost. A further point that is immediately implied is that it is questionable to attempt to design a universal switching system which is applicable to the entire range of service requirements. There are at present, and probably always will be, several distinct and different switching systems, each for use in a particular field of application.

In order to illustrate what is involved in engineering a local central office, and how the engineering flexibility affects the design, a particular system will be briefly described and the engineering technique to apply this system to a typical set of conditions will be discussed. The discussion is not exhaustive, nor is it intended to offer a set of rules for engineering; rather, the purpose is to indicate the general principles that are involved and the provisions that must be made during system design to permit such engineering. The system chosen for this discussion is No. 5 Crossbar, since it is the latest example of switching design technique. In order to keep the chapter within bounds, many features available in No. 5 Crossbar will not be considered. The most important of the features omitted are the facilities for AMA charging, toll and tandem switching, operator switchboards, trouble recording and test equipment, and the power plant.

12.2 DESCRIPTION OF NO. 5 CROSSBAR

Figure 12-1 shows the important equipment units of the No. 5 Crossbar System and their interrelationship. From the standpoint of the basic principles, this switching system belongs to the category of common control marker systems discussed in Chapter 6. Therefore a brief description of the equipment units and the operating features should be adequate for present purposes.

The system was designed primarily to serve the residential sections of large cities and the fringe areas around these cities. In regions of this type a relatively large proportion of all calls are completed to subscribers within the same office. Furthermore, the surrounding offices to which connection must be made are likely to be of widely diversified types. Both these factors had a predominant effect upon the design of No. 5 Crossbar. However, the system is also capable of serving isolated centers from about 3000 lines up, and multioffice areas including the largest metropolitan business exchanges.

In addition to its use as a local switching office, the No. 5 Crossbar can also be used for toll and tandem switching.

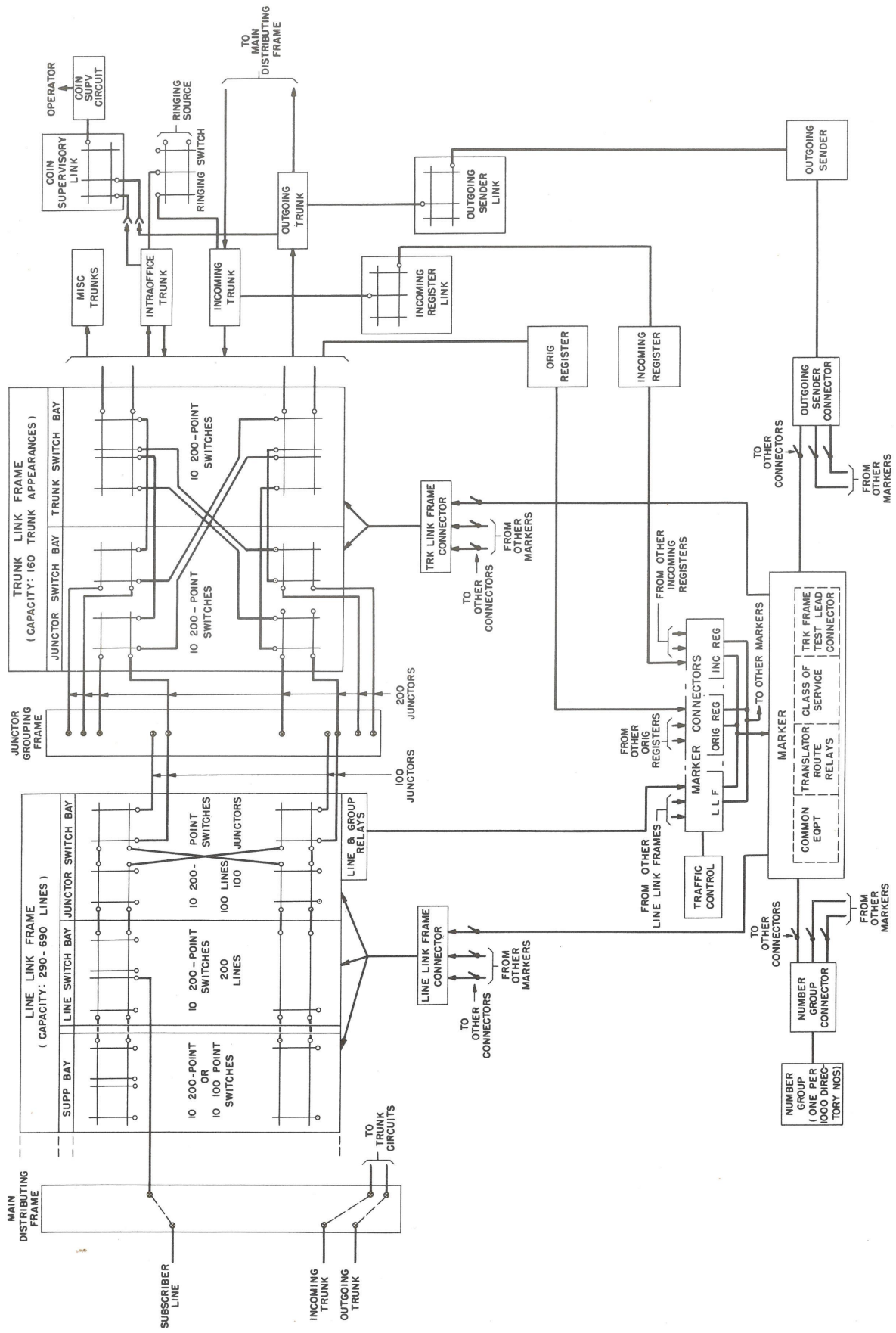


Figure 12-1 Equipment Schematic of No. 5 Crossbar System

The Interconnecting Network

The two types of switching grids that perform the interconnecting function are known as the Line Link Frame and the Trunk Line Frame. All subscriber lines terminate on crossbar switch line link frames, and all trunks and registers connect to crossbar switch trunk link frames. Junctors interconnect each line link frame with every trunk link frame so that each subscriber line has full access to all trunks and registers. Line link and trunk link frames are illustrated on Figures 12-2 and 12-3.

The basic line link frame accommodates 290 subscriber lines connected to the crossbar switch verticals of the line switch bay and the left-half switches of the junctor switch bay. Although 300 line terminals are provided, 10 of these are reserved for a special feature. Additional groups of subscriber lines up to a maximum of 690 can be taken care of by multipling supplementary switch bays to the horizontals of the basic line switch bay. One hundred line links interconnect the line switches and junctor switches in the standard crossbar grid pattern. Wired to the verticals of the junctor switches are 100 junctors which are distributed equally to the trunk link frames.

Each trunk link frame provides 160 trunk terminals on the horizontals of the ten trunk switches. The trunk switches interconnect with the junctor switches of the frame by means of 200 trunk links, again in a standard grid pattern. The junctor switches provide termination for 200 junctors from line link frames. Junctors that connect to the left half of the junctor switches can match only with the left group of links to the trunk switches. The right junctor groups, in turn, match only with the right links.

Since trunk link frames provide twice as many links and junctor terminations as line link frames, there are usually twice as many line link frames in an installation as there are trunk link frames. For the basic frames there is a natural maximum limit of twenty line link frames and ten trunk link frames. With this number, ten junctors interconnect each of the two types of frame. Increase in the number of frames up to forty and twenty, respectively, is possible by providing extension junctor switch bays on the trunk link frames and by multipling junctors, but this arrangement will not be discussed in this chapter.

When the number of frames in an installation is below the twenty-ten size, the number of junctors between frames of each type exceeds ten (for example, in a ten-five size office each group comprises twenty junctors). When this occurs, the junctors of a group are subdivided into sets of ten for channel matching purposes, each set distributed over the ten junctor switches of the frame and connecting consistently to either the left or right side of the switches. If there is any remainder after dividing into sets of ten, the excess is kept in a partial set. The Junctor Grouping Frame is provided to facilitate the wiring of the junctors between frames.

The switching frames provide for connections in two directions. When a subscriber places an outgoing call, the connection is established from the line on the

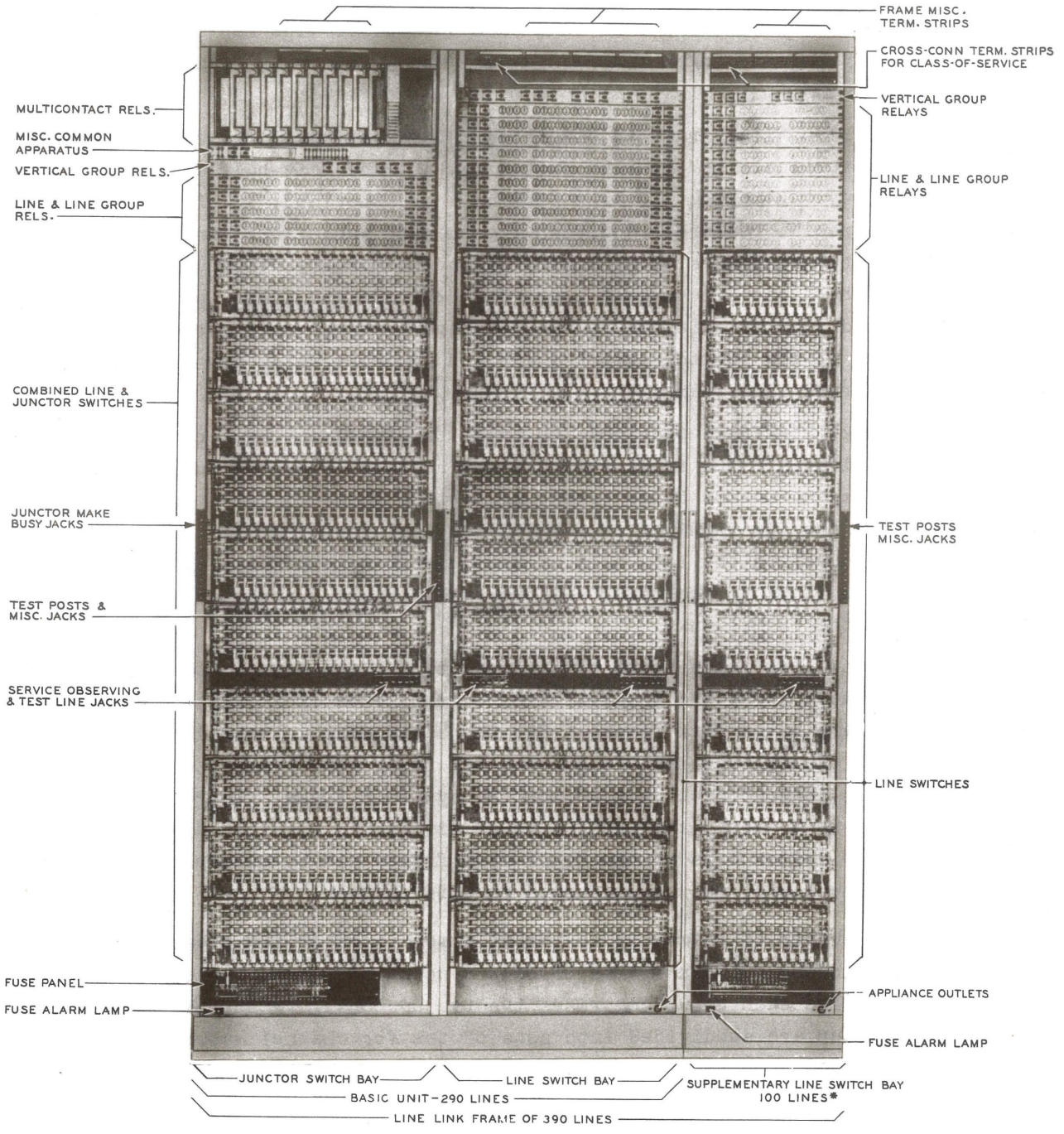


Figure 12-2 Line Link Frame

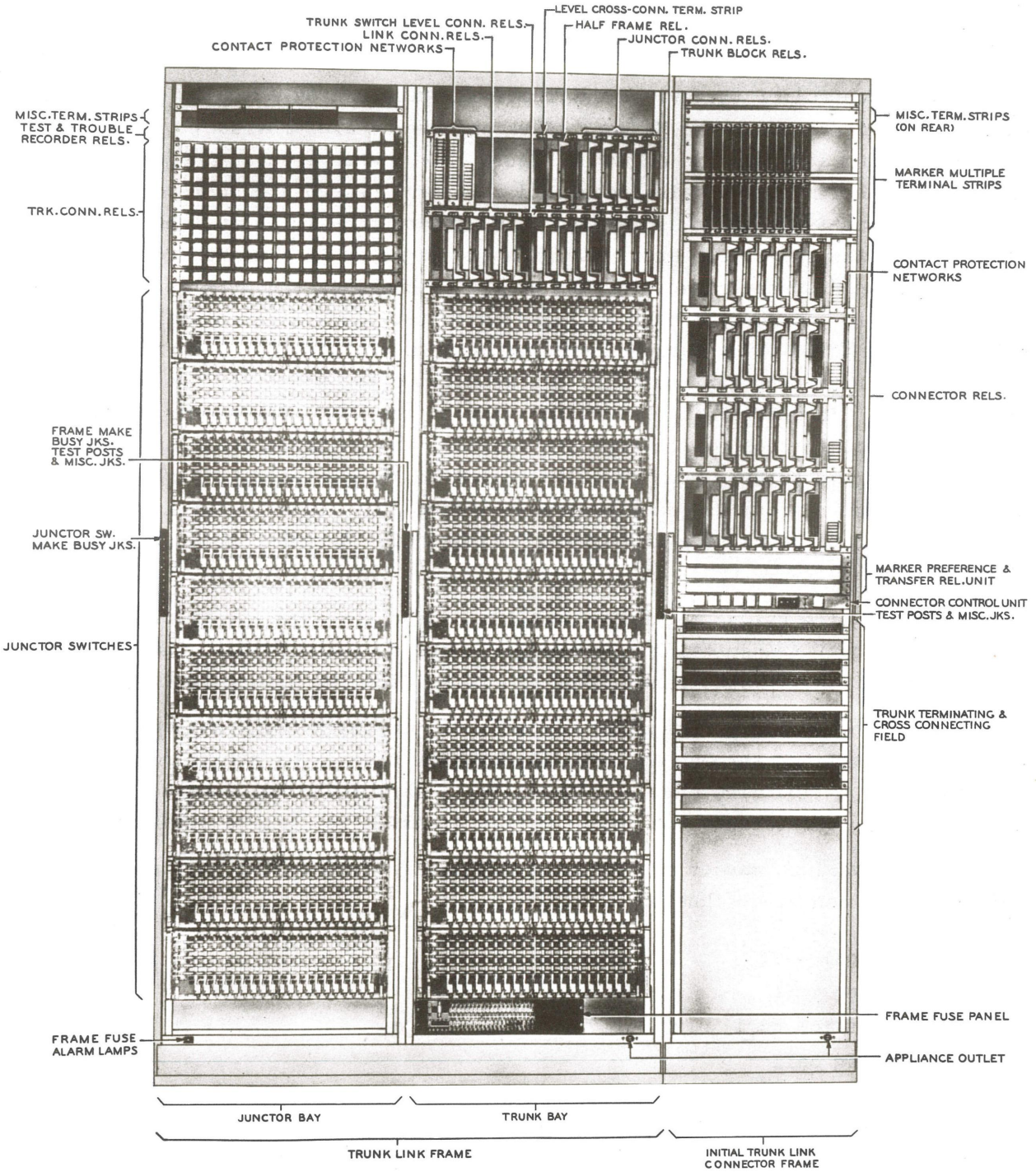


Figure 12-3 Trunk Link Frame

line link frame to an outgoing trunk on the trunk link frame. The connection for an incoming call, on the other hand, is established from the trunk on the trunk link frame to the line. Intraoffice calls involve connections in both directions, from calling line to trunk and from trunk to called line. The same switching frames are also used to connect registers to subscribers for the reception of dialed instructions.

Control—The Marker

Sole control of the switching frames is exercised by a single type of common control circuit known as the Marker, of which several are provided. The several bays comprising a marker are shown on Figure 12-4. When a subscriber originates a call, the line link frame gains access to a marker through a marker connector. The marker, recognizing that it is serving an originating call, establishes a connection between the subscriber and an Originating Register in a manner to be described later. When the subscriber has completed dialing, the originating register gains access to a marker through a marker connector and passes the calling and called number to it. The marker thereupon sets up a connection from the calling line to either an outgoing trunk or, via an intraoffice trunk, to the called subscriber line. In determining the destination of the call, the marker utilizes an internal translator for office code translation, and on incoming or intraoffice calls, a separate Number Group for line number to line location translation. An individual number group for each numerical set of 1000 lines is furnished with access thereto by means of a Number Group Connector. A number group frame is shown on Figure 12-5.

On outgoing calls the marker must also associate with the trunk an Outgoing Sender capable of transmitting information to the distant office. The trunk-sender connection is established by means of the Outgoing Sender Link.

On incoming calls from other offices, the incoming trunk connects itself to an Incoming Register through an Incoming Register Link. The register, after receiving the called line number, connects to a marker through a marker connector and the marker establishes the path from the trunk to the called subscriber line.

These various marker operations are classified according to the type of job performed and can be designated:

Dial tone call
Outgoing call
Intraoffice call
Incoming call

The sequence of events that takes place on each type of job will be described briefly in a later paragraph. Because of the comprehensive nature of the marker control, it will be found that this description will include most of the operating features of No. 5 Crossbar.

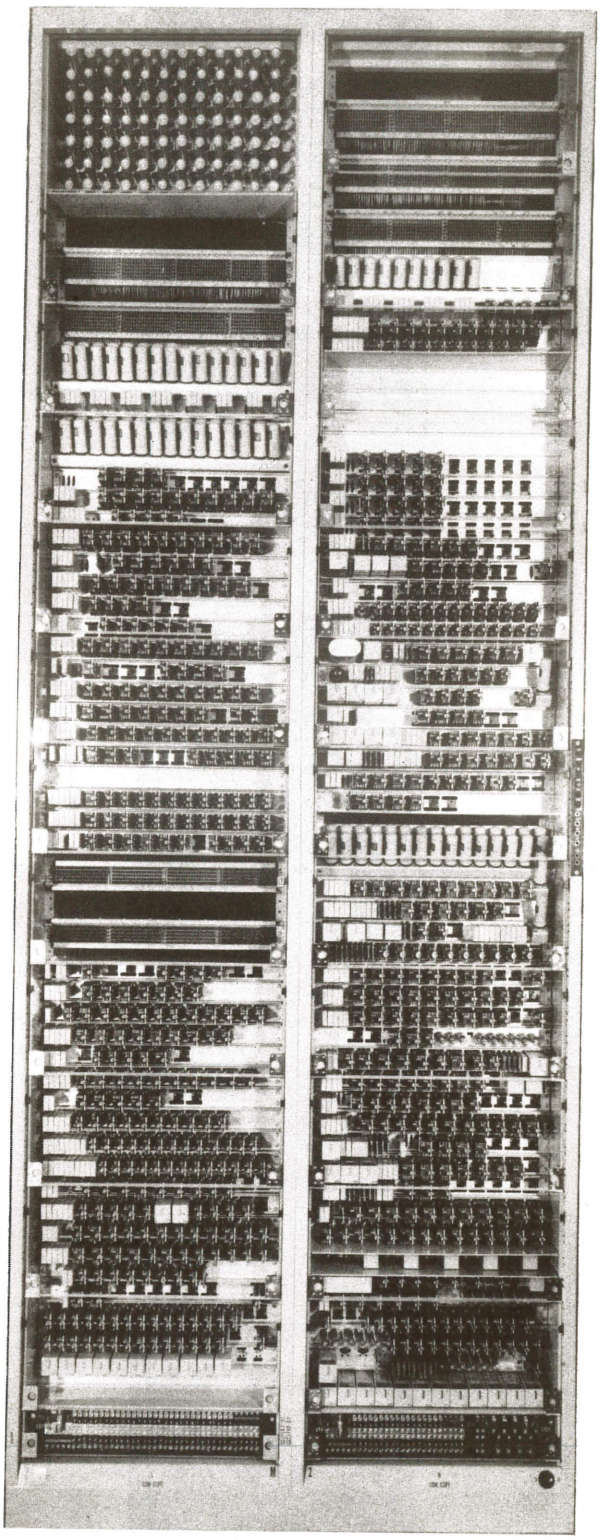


Figure 12-4A Marker Equipment—
Common Equipment Frame

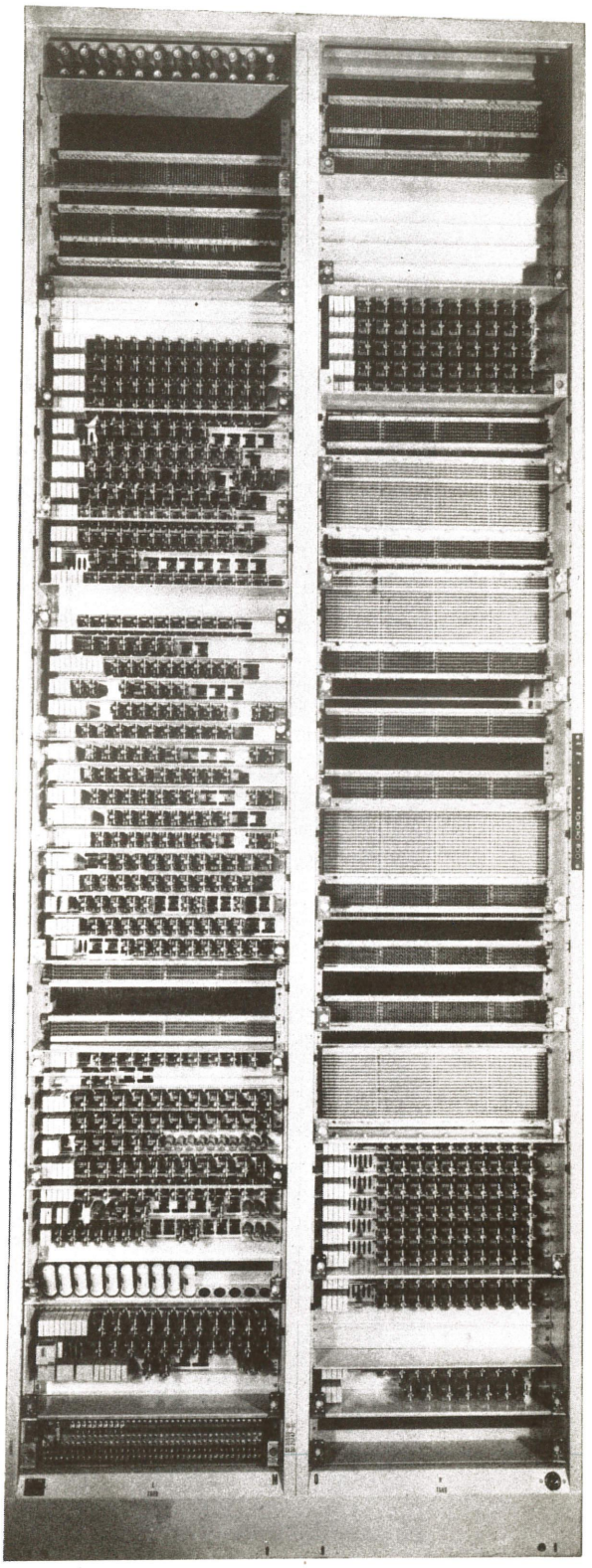


Figure 12-4B Marker Equipment—
Translator and Route Relay Frame

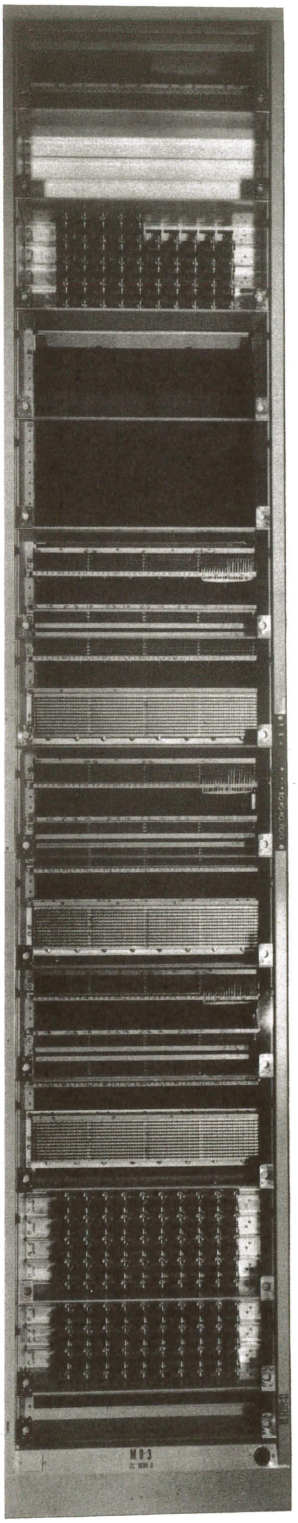


Figure 12-4C Marker Equipment—
Class-of-Service Bay

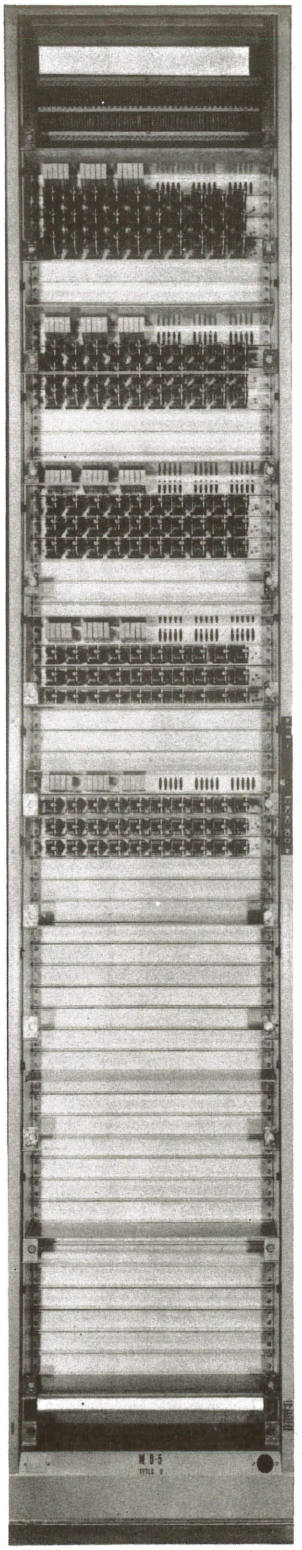


Figure 12-4D Marker Equipment—
Trunk Frame Test Lead Connector Bay

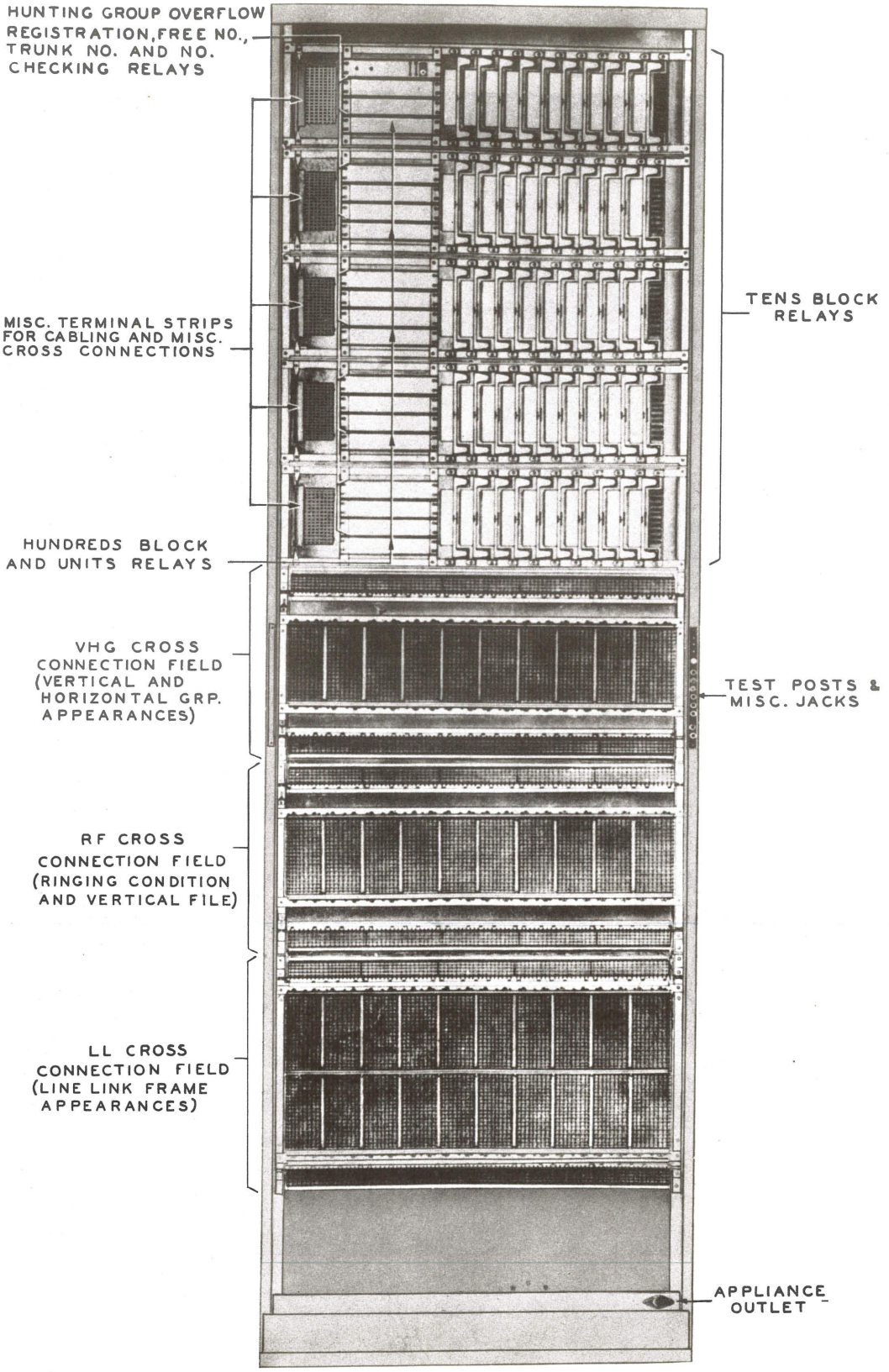


Figure 12-5 Number Group Frame

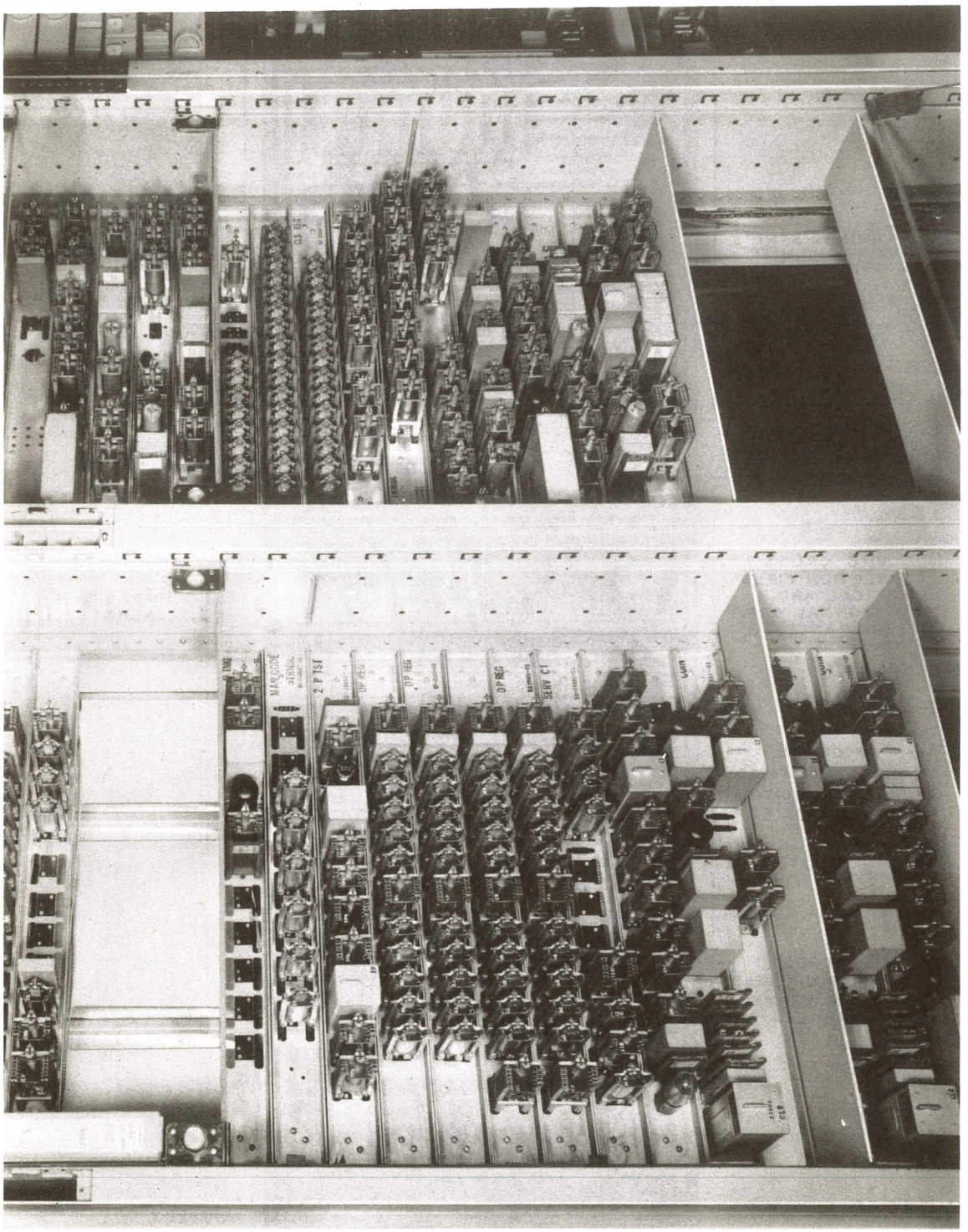


Figure 12-6 Originating Register

Registers

The originating register shown on Figure 12-6 receives and records the dialed information from the calling subscriber. It also determines, when required, which of the parties on a two-party line is calling, and on coin lines, whether the coin is present. While the marker is establishing the connection between line and register, it records in the register the equipment location and class of service of the line for use when the register recalls the marker at the end of dialing. The originating registers are disposed over the trunk link frames in the same manner as trunks.

Incoming registers, which receive information from distant offices over the incoming trunks, are of three types, corresponding to the type of signaling employed. Dial pulse registers accept dial pulse type signals, usually from step-by-step offices. Revertive pulse registers function with Panel or No. 1 Crossbar offices, and the multifrequency type registers with other No. 5 Crossbar offices or any office equipped for this type of signaling. After the called line number has been recorded in the incoming register, the latter connects to a marker for establishing the connection between line and trunk.

Trunks

Each type of call in No. 5 Crossbar utilizes a particular type of trunk circuit, the circuit primarily consisting of the transmission, supervisory, charging, and ringing equipment. The three main types of trunks are designated outgoing, intraoffice, and incoming. In addition, there are special trunks for toll calls, operator and service calls, trunks to return tone signals, and the like. Most of these correspond to outgoing trunks. A pair of trunks are shown on Figure 12-7.

The intraoffice trunks comprise one large group with a common destination. The outgoing trunks, on the other hand, are broken down into many individual groups, each with a different destination. The trunks of each group are

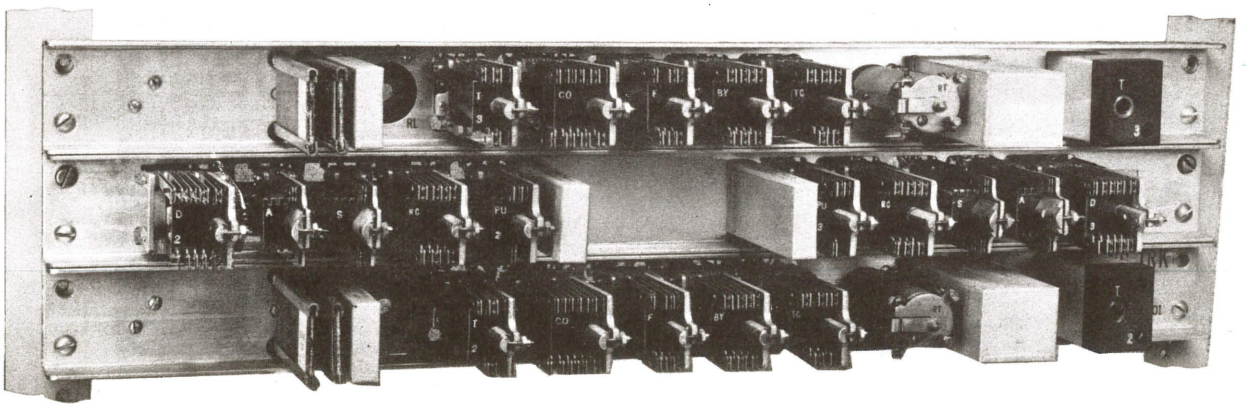


Figure 12-7 Trunk Circuits—Two Mounted Together



Figure 12-8 Outgoing Sender—Dial Pulse Type

distributed as equally as possible over all trunk link frames. To facilitate trunk testing by a marker, trunks in the same group on a frame supply over a common lead an indication of their group busy or idle condition. This group indication is in addition to the individual busy test leads.* Thus the marker is enabled to test trunks first as frame groups and then, after gaining access to an idle trunk link frame with idle trunks, as individuals of a group. This arrangement permits all trunks of a group to be engineered as a single large group. Originating registers are handled by the marker in the same manner as a trunk group.

Intraoffice and incoming trunks, unlike outgoing trunks, must include provisions for ringing the called subscriber. Each of these trunks is connected to a vertical on a ringing selection crossbar switch. This makes available, under control of the marker, any one of a variety of ringing codes as specified by the number group translation of the called line number.

Intraoffice trunks, of course, must have two appearances on the trunk link frame in order to connect to both the originating and the terminating subscriber. However, a special variety of intraoffice trunk, the reverting trunk, used to enable two parties on the same line to talk, requires only one appearance.

Outgoing Senders

Outgoing Senders, which connect the outgoing trunks in order to transmit information to a distant office, are of several varieties depending upon the type of signaling required. They are designated dial pulse, revertive, P.C.I., and multifrequency. A sender is associated with an outgoing trunk by means of an Outgoing Sender Link and with a marker through an Outgoing Sender Connector. An outgoing sender is shown on Figure 12-8.

Coin Supervisory Circuit

Trunks arranged for the handling of calls from coin stations connect themselves to a Coin Supervisory Circuit whenever it is necessary to collect or return a coin. The charge condition is set in the trunk itself when the called subscriber answers. At the time that the calling subscriber disconnects (or at the end of four and one-half minutes if the trunk is arranged for overtime charging), the trunk connects to the coin supervisory circuit. The latter circuit impresses the coin collect or return voltages upon the trunk, depending upon the charge condition. The circuit also makes tests for the presence or absence of the coin before and after collection, and if conditions are not correct, connects the call through to an operator.

Connectors and Links

In order to provide access between control circuits and the rest of the system, connectors and links are provided. The connectors give access to and from the

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***If the number of trunks in the same group exceeds twenty per trunk link frame, the group is split and the frame subgroup common busy leads are tested separately and consecutively.**

markers and are designed to accommodate a maximum of six markers. When more than six markers are required, supplementary connectors are used. The links provide access between trunks and certain control equipment.

Paths to the markers are carried through marker connectors, of which there are three types. A line link marker connector gives access from each line link frame to all markers. Originating register and incoming register marker connectors give access to the markers from the respective types of registers, taken in groups whose size depends upon traffic conditions. The relays comprising the register end of these marker connectors are mounted on the register frame.

Since all types of calls must utilize the same group of markers for control purposes, it is necessary to prevent any small group of marker connectors from monopolizing the markers during periods of heavy traffic. To this end a common traffic control circuit is associated with all marker connectors and serves to regulate traffic through them. When traffic is heavy, the circuit permits only one call per connector to be served until all connectors with waiting calls have been served once. Then the so-called "gate" is opened and all connectors are served again on the same basis. Line link frame connectors are assigned highest preference for markers. Next in order come the originating register connectors, and finally the incoming registers. In lighter traffic, the traffic control feature has little effect and the marker connectors allot calls equitably to idle markers.

For setting up connections through the network, the markers must gain individual access to the line link and trunk link frames. This access is provided by the line link frame connectors and trunk link frame connectors, one of which is associated with each frame. A trunk link frame connector is shown on Figure 12-3. The frame connectors include lockout circuits which permit only one marker to enter a frame at a time for control purposes.

The number group connector is similar to the frame connectors. Each connector gives access from the marker to one of the number groups which comprises the translating equipment giving information on line location, type of ringing, PBX hunting, and so forth, for 1000 lines in a particular numerical thousand group. Again, only one marker is permitted to connect to a particular number group at a time.

Outgoing sender connectors enable markers to connect to senders for the handling of outgoing calls. Since the sender relays of the connector are located on the sender frame, the number of senders that a connector can accommodate is limited only by traffic considerations. For reasons of safety and to speed up service, the senders of a particular group (consisting of one type of sender) are always split between at least two connectors so that two markers can simultaneously serve calls requiring a particular type of sender. Outgoing senders of different groups can be placed on the same connector.

The outgoing sender link shown on Figure 12-9 provides access between outgoing trunks and senders under control of the marker. The link utilizes crossbar

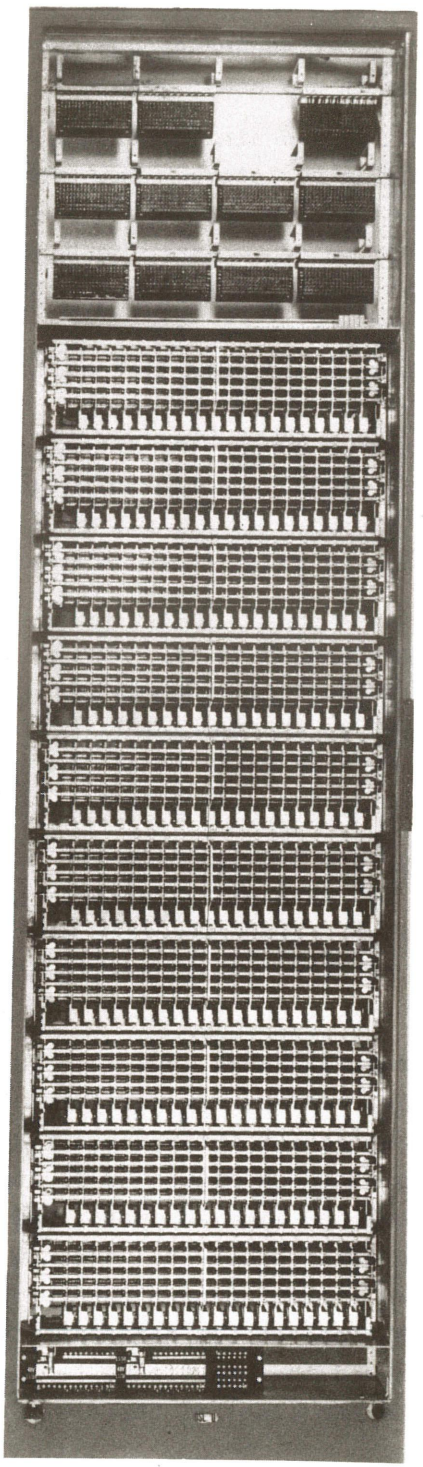


Figure 12-9 Outgoing Sender Link

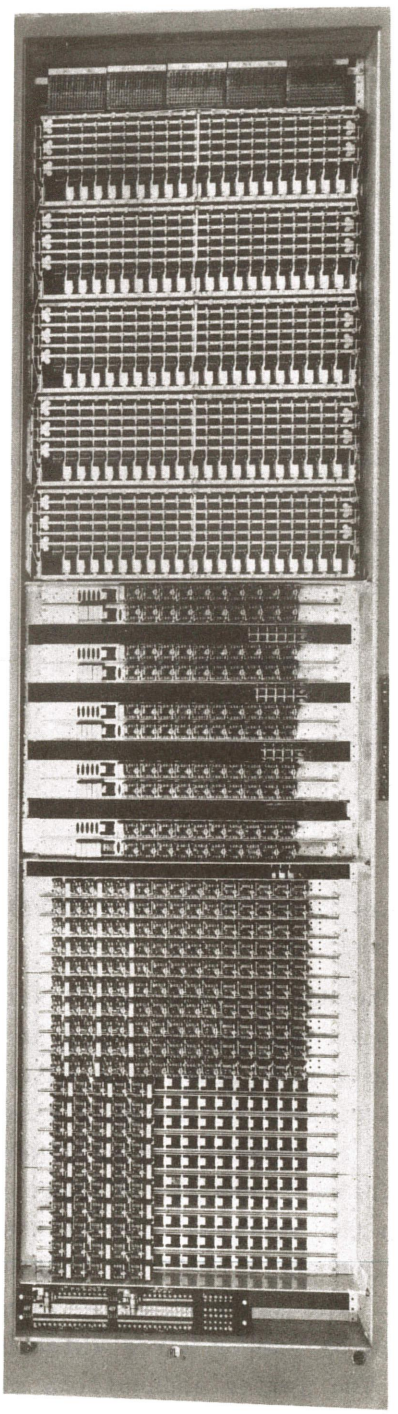


Figure 12-10 Incoming Register Link

switches, with trunks connecting to the verticals and senders to the horizontals. The senders can be multipled to as many switches or partial switches (with split horizontal multiple) as are necessary to load the senders. Since each trunk requires a particular type of sender as determined by the connecting office, the correct association of trunks and senders on the link switches is important. Wiring the senders to the link switch horizontals limits the sender group size to ten. However, if more than ten are required, additional sender groups can be installed and the trunks can be associated with one or the other group.

Incoming register links, shown on Figure 12-10, are similar to the sender links and serve to connect incoming trunks to incoming registers. The trunks are wired to the crossbar switch verticals, while the registers connect to the horizontals so that again register group size is limited to ten. Incoming registers are multipled to as many switches as are necessary to provide adequate load. Since the incoming register link operates under control of the trunk rather than the marker, a preference and control circuit is associated with each link switch. On incoming calls from a step-by-step office on which the subscriber dials, it is necessary to connect the incoming trunk to the register during the interdigital period. Since the crossbar switch may not function rapidly enough to insure this, the pulsing leads of these trunks are also wired through link control relay contacts which provide "by-links" to establish temporary connections to the register until the switch path is set up.

The coin supervisory link which connects coin trunks to the coin supervisory circuits is almost identical with the incoming register link. Supervisory circuits are wired to the link switch horizontals, and trunks to the verticals.

Distributing Frames

Subscriber line and interoffice trunk conductors terminate in the central office on a large cross-connection frame known as the Main Distributing Frame (MDF). The principle function of the MDF is to facilitate the interconnection of the lines and trunks with the correct terminals on the line link and trunk link frames respectively.

The MDF is constructed with two sets of terminal blocks, one set mounted in horizontal rows and the other in vertical rows. Between the rows of terminal blocks is a metal framework which supports jumper wires for interconnecting the rows. A picture of the main distributing frame is shown on Figure 12-11 and a schematic representation on Figure 12-12. The trunk and line conductor pairs are wired directly from the outside cables through protector blocks to permanent positions on the vertical side of the MDF. Switchboard cables connect the terminals on the line and trunk link frames to permanent positions on the horizontal side of the MDF. The association between lines and trunks and the link frame terminals is performed by jumper wires which are run between the two sides of the distributing frame. The jumper connections must of course be closely coordinated with the number group and other cross-connections which specify to the control circuits the equipment location of each line or trunk. Certain vertical terminals on the frame



Figure 12-11 Main Distributing Frame

are assigned to message registers and number group PBX test leads when required by the office, and the sleeve terminals of message rate and PBX lines are "jumpered" to these.

Although the jumper connections for all working lines and trunks must be made on the MDF during installation of the central office, continual changes are required during the life of the office as lines and trunks are added, removed, or reassigned. The design of the frame is such as to facilitate such changes.

The Junctor Grouping Frame is the interconnection point between the line link and trunk frames. The leads from each frame are wired to terminal strips to facilitate the interconnection. In an office with twenty line link frames and ten trunk link frames, the junctor leads from each type of frame connect directly to opposite sides of the same terminal blocks so that jumpers are unnecessary. For size offices, the basic junctor connections (one group of ten junctors between each line link and trunk link frame) are made as above, but the additional groups are interconnected with jumpers. The junctor grouping frame is wired at the time of installation; if frames are added during the life of the office, jumper connections are changed. An additional grouping frame is required if the office exceeds the twenty-ten size.

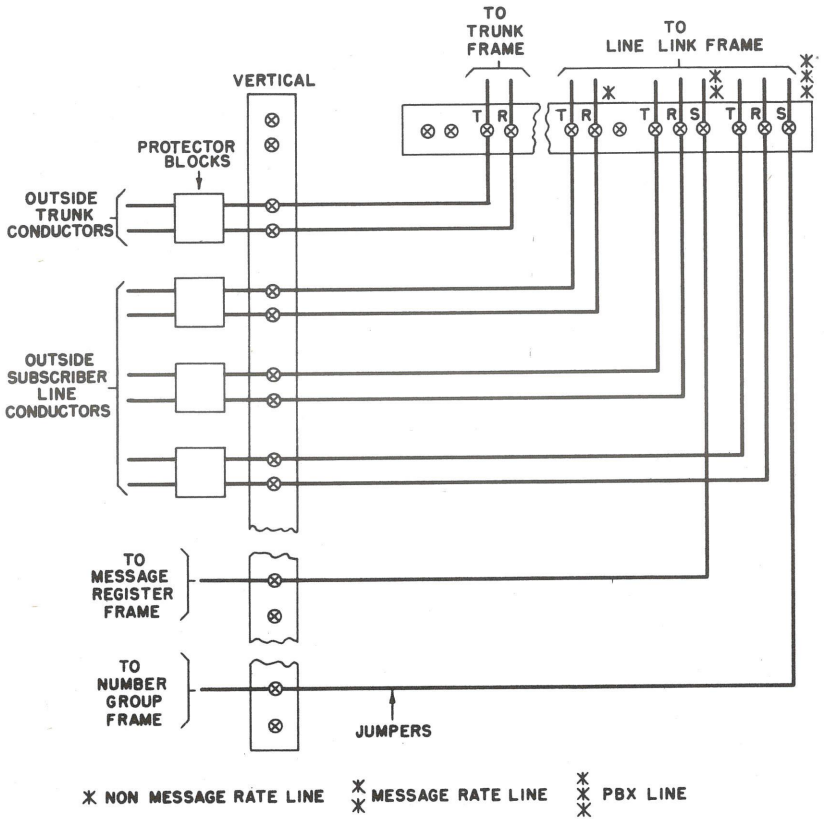


Figure 12-12 Main Distributing Frame—Cross-Connections

12.3 DESCRIPTION OF TYPICAL CALLS

Dial Tone Call

On all originating calls in No. 5 Crossbar the calling line must first be connected to an originating register. When the subscriber initiates the call, the line relay on the line link frame operates and signals the line link frame marker connector to put in a bid for a marker. When the marker is connected, it

identifies the calling line location on the frame in terms of frame number, vertical group (columns of switch verticals 0-13, each column five verticals wide), horizontal group (switch level 0-9) and vertical file (switch vertical 0-4 within a vertical column. The marker also records the class of service of the line (this is assigned by a cross-connection on the line link frame), and the fact that the connection must be set up to an originating register. If several subscribers on the same frame are originating simultaneously, the marker selects one line on a rotating preferential basis, although absolute preference is always given to one particular vertical group.

At the same time that it is making line identification, the marker operates the route relay which specifies the trunk link frame location of originating registers. It then determines which trunk link frames are idle and have idle registers by examining the register group busy and frame busy test leads. The marker connects to an idle frame with idle registers through the trunk link frame connector and seizes a particular register. The location and class of service of the calling line is then transferred to the register.

After gaining access to the trunk link frame, the marker seizes the link link frame through the line link frame connector. It now has control of the two ends of the connection and the intervening links and junctors. The marker attempts to match a channel between line and register and if successful, closes the switch crosspoints, checks the established path for continuity and against double connections and disconnects itself. If the marker cannot match a channel, it releases the register and link frame and makes another attempt, starting with the test of register groups and trunk link frames. A second mismatch causes the marker to release itself so that the line must start out again as though it were a new call. If all registers test busy, the marker also releases the call.

When the path has been established between line and register, the register tests for party identification or presence of a coin if required by the class of service, and then applies dial tone to the line. When the subscriber has dialed an adequate number of digits, the register connects itself to a marker through a marker connector for the second stage of the call.

Outgoing Call

If the call is to another office, it is classed as an outgoing call. When the originating register is connected to the marker, it transfers to the latter the complete dialed number and the location and service class of the calling line. The called office code together with the calling class of service indication enables selection within the marker of the route relay corresponding to the correct trunk group and arranges for appropriate charging. The route relay specifies both the trunk group location on the trunk link frames and the associated outgoing sender group.

In a manner similar to that followed on a dial tone call, the marker determines that there is an idle trunk link frame with idle trunks and that a sender is available. It first gains access to a sender through the outgoing sender connector

and then seizes a trunk link frame and chooses a particular trunk. When the connection to the trunk link frame is established, the marker connects to the line link frame on which the calling line is located. Through paths via the trunk and sender the marker controls the outgoing sender link to interconnect trunk and sender. It also transfers to the sender the called line number via the outgoing sender connector.

Through the line link and trunk link frame connectors, the marker tests the group of channels between line and trunk. In order to improve the probability of matching, it includes in the test as idle the line link currently in use between line and register. If an idle channel is found, the marker releases the line-register channel and establishes the new connection to the trunk. After checking the integrity of the connection, and setting, if necessary, the correct party or coin charge condition in the trunk, the marker releases itself. The sender thereupon makes a test of the trunk path to the distant office and, if satisfied, transmits the called line number to the distant office and disconnects.

When the marker is unable to match a channel to the trunk, it chooses a new trunk and sender combination and repeats the call attempt. A second mismatch causes the marker to choose an alternate route trunk if available, and, if not, an overflow tone trunk. A third mismatch always results in the overflow tone signal, and the coin-return signal if necessary, being applied by the still-connected register.

An all-trunks-busy or sender-busy condition causes the marker to test alternate route trunk groups up to a maximum of three. When all alternate route trunks are found busy, the call is connected to an overflow tone trunk. As a final resort, the register will return the tone signal to the subscriber.

Certain outgoing trunks such as those to operators, information and repair desks, and the like, do not require the use of an outgoing sender. The handling of the call, except for the sender connection, is the same as that described above. Since there is no charge for such calls, if a coin line is originating the register returns the coin immediately upon receiving the dialed digits.

Intraoffice Call

Calls to a subscriber within the same office are completed through intraoffice trunks. When, on such a call, the register has obtained a marker and transferred to it the called number and the location and class of service of the calling line, operation of the route relay specifies the intraoffice trunk group with the correct charging equipment. The marker connects to an idle trunk link frame with idle trunks and chooses a particular trunk.

Next, the marker seizes the number group determined by the "thousands" digit of the called line number and obtains from it the called line location and the type of ringing required. If the called line number is in a PBX group, the number group makes available the sleeve leads of the group for test so that the marker can select an idle line. From the information received from the number group, the

marker connects to the line link frame bearing the called line and tests the line for busy. If it is idle, the marker establishes a channel between line and trunk.

This line link frame is then dropped and the marker connects to the one containing the calling line. Again the marker tests the channels (including as idle the line link used in the register connection), selects a matched channel, and establishes the second half of the connection. After setting the trunk ringing switch as specified by the number group information and after establishing the appropriate charging condition in the trunk, the marker releases.

If the marker, is unable to match a channel on either half of the connection, it makes a second attempt, using a different trunk if possible. A second mismatch results in a connection to an overflow tone trunk, and a third in a tone signal from the register. If a line or intraoffice trunk-busy condition is encountered, the marker sets the call up to a busy or overflow tone trunk. If these are all busy, again the register can supply the appropriate tone signal.

A particular type of intraoffice call must be handled somewhat differently from the method described above. This condition occurs when a subscriber calls another party on the same line and is known as a reverting call. The marker does not recognize the situation until after it has seized an intraoffice trunk and connected to the number group. It must, therefore, drop the trunk and trunk link frame and go after a reverting trunk to which the single line embracing calling and called subscribers can be connected. The reverting trunk contains special provisions for signaling the two subscribers.

Incoming Call

A call arriving from another office is known as an incoming call and differs from outgoing and intraoffice calls primarily in that it requires but one marker usage. When a call arrives on an incoming trunk, the trunk must first associate itself with an incoming register which can receive the terminating line information. The trunk gains access to the appropriate type of register through the Incoming Register Link. When the line number has been recorded, the register seizes a marker through the marker connector and transfers to it the line number and the location of the incoming trunk.

The marker connects to the particular trunk link frame bearing the trunk in question, and when it is assured of this connection, it seizes the number group. The number group supplies the location and type of ringing of the called line, enabling the marker to connect to the correct line link frame. If the line tests idle, the marker chooses an idle channel and establishes a connection between line and trunk. After checking the connecting path and setting the trunk ringing switch, the marker releases.

When the line tests busy, or if no idle channel can be found (since both trunk link and line link frames are fixed, no second matching attempt is justified), the marker sets the incoming trunk to return the appropriate signal to the originating office.

Trouble Conditions

As in all telephone switching systems, there are several features in the No. 5 Crossbar System whose purpose is to insure that calls get through, if possible, in spite of trouble conditions. In addition, to facilitate maintenance, the circuits are designed to give positive indications of troubles encountered. The trouble indications are given by means of punched card records, visual and audible alarms, and trunks to special test or operator positions.

If a marker encounters trouble in setting up any call, its usual procedure is to have a punched card record made by means of the trouble recorder and then to give a trouble release signal. On dial tone calls this causes the line link marker connector to release and make a new attempt. In general a different marker will be obtained. On outgoing and intraoffice calls, after an initial trouble release the register makes a new request for a marker and informs it that it is a second trial. The marker changes certain preferences and cancels some tests in the second attempt to complete the call. If the second trial fails, the originating register is directed to return a tone signal to the subscriber. Incoming calls are handled in the same fashion, with the trunk returning an overflow signal after two failures.

12.4 ENGINEERING THE CENTRAL OFFICE

In this section the procedures involved in engineering a No. 5 Crossbar office to meet a particular set of circumstances will be outlined.

The purpose of the discussion is threefold. First, an indication will be given of the type of decisions that must be made in traffic engineering, and the factors that affect such decisions. Second, the purpose is to illustrate the specific techniques that are used in determining equipment quantities, including the use of traffic tables. Finally, the underlying purpose is to give some appreciation of the extent to which the circuit designer must bear in mind traffic factors during the design process. This is not discussed as a separate point but is continuously and strongly implied by bringing out quantitative relationships and optional features.

Related to the job of traffic engineering is the choice of the various circuit options that will enable furnishing the required type of service. For example, not all central offices provide coin or party service, and where such services are necessary, particular circuit options must be specified in certain of the equipment units. Other conditions involving circuit options are methods of charging other than coin, number of digits required for signaling, number of classes of service, and so forth. The choice of circuit options will be discussed concurrently with the determination of equipment quantities in the engineering example, although no attempt will be made to specify such options completely.

The engineering example will go into considerable detail insofar as the major central office equipment units are concerned. However, the over-all problem will be simplified by confining outside traffic to a limited number of surrounding

offices and by omitting from consideration all but the intraoffice and outgoing trunk groups. Many minor details that in practice must be considered will be either omitted or merely mentioned in passing. No attempt will be made to justify certain of the basic traffic figures that will be assumed.

The set of traffic requirements to which the sample central office will be engineered is not necessarily representative or typical. For the most part, the requirements were chosen to bring out certain points of interest.

General Considerations

The first step in engineering a central office is to establish the service standards that are to be met and to determine the type and volume of traffic that must be handled during the busy hours. The service standards, the type and volume of traffic, and the type and quantities of equipment are related to one another through the medium of traffic tables which constitute the chief tool in traffic engineering.

The choice of service standards, the chief elements of which are speed of dial tone, number of overflows encountered, and the speed of completion, is based largely on intangible factors. It depends to a great extent on what subscribers are accustomed to, the service offered in neighboring communities or central offices, and the general use to which the telephone service is put. For example, subscribers served by a perhaps underloaded central office, where dial tone is invariably received immediately, are likely to complain severely if a new office provides slight dial tone delays. On the other hand, subscribers shifting from manual service to automatic may be more lenient in their attitude. A central office serving a commercial or business district may have to provide faster dial tone service and fewer overflows to satisfy its customers than a purely residential central office. The traffic engineer must carefully evaluate all these factors, and many more, to arrive at an adequate set of service standards.

A generally accepted standard for good service that applies in the majority of situations provides that no more than one per cent of originating calls should suffer a dial tone delay of greater than three seconds, and that only one call out of one hundred should encounter an overflow condition on the trunk groups or switching paths. These figures apply, of course, to the busy hour of the busy season rather than to periods of average traffic. It is on this basis that the engineering example of this chapter will be handled.

Determination of the volume of traffic is often a difficult job that entails considerable reasoned guesswork. It primarily involves traffic counts taken during the busy hour of certain days during the busy season. Not only is it necessary to arrive at figures representative of total originating calls, but also the distribution in accordance with destination. Busy-hour traffic tends to fluctuate rather widely from day to day and week to week. It is not economical to engineer for the extreme busy hour of the year, so that some average must be arrived at. However, account must be taken of the frequency and extent of the occasions which may exceed the busy-hour figure that is taken as the engineering base. Circumstances

may require additional equipment to prevent undue deterioration of service during comparatively infrequent, but foreseeable, periods during the year.

In addition to traffic volume in terms of number of calls, it is also necessary to know the average holding time for calls. Certain categories of holding time, such as that required for dialing, are relatively constant, while conversation time, at least on local connections, has an exponential distribution. Holding time information is obtained from past service observations on the subscriber group or is derived from similar groups in other central offices.

A central office is engineered, not for the traffic situation of the moment, but for some time in the future, perhaps two years, known as the engineering base period. Thus all the traffic estimates must be projected through the engineering period, taking into account such factors as population growth, neighborhood and real estate trends, possibility of integration into metropolitan numbering plans, and the like. In the engineering example to be given, all these factors will be assumed to have been taken into account.

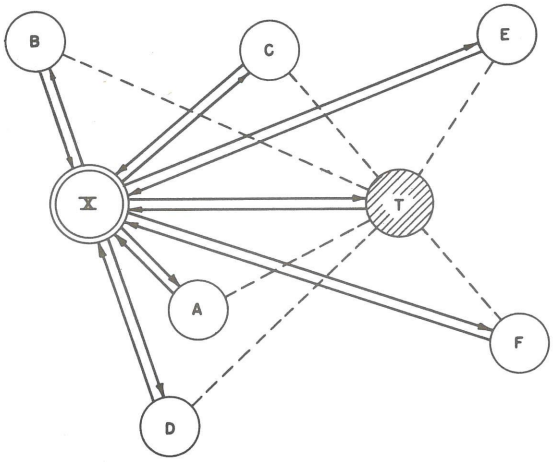


Figure 12-13 Relation of Office X to Adjacent Offices

For use in traffic engineering, the busy-hour estimates of number of calls and holding times must be combined into traffic load figures which are usually expressed in terms of "CCS per busy hour" as discussed in Chapter 2. Traffic tables, based on certain simplifying assumptions of the flow of telephone traffic, relate load in CCS to the number of circuits required to give a desired grade of service.* The most frequently used tables are subdivided according to the probability of a particular call encountering all circuits busy, where this probability can be taken as the definition of grade of service.** The numerical designation of each table indicates the probability value multiplied by one thousand. For example, the column headed Table 10 gives the traffic load in CCS that can be carried by different numbers of circuit paths in a group with a probability of loss of ten calls in one thousand.

Engineering Basis for Sample Central Office

Office X is to serve a community located amongst a group of similar communities which are served by offices A, B, C, D, E, and F. Associated with these

*For some of the mathematics underlying traffic engineering, see the text of the companion course: Probability and Statistics.

**Restated, the grade of service is the proportion of calls blocked because all accessible paths in a desired group are busy.

local offices is a tandem office, T. The physical relationship of office X to the other offices is shown on Figure 12-13, together with the trunking between offices from the point of view of X. The estimated traffic conditions to which office X must be engineered can be listed as follows:

Number of lines	7000
Directory numbers (A separate directory number is assigned to each subscriber on a multiparty line.)	9200
Number of busy-hour originating calls	11,500
Partially dialed calls (This is included in the busy-hour originating calls.)	800
Number of good originating calls (11,500–800)	10,700
Average holding time for all completed calls (This is the time from the establishment of the talking channel until disconnection.)	115 seconds
Average holding time for originating registers (This is primarily dialing time.)	13.5 seconds
Distribution of traffic in per cent of good originating calls	
Intraoffice calls	60%
Outgoing calls (including operator, etc.)	40%
Incoming calls (equal to outgoing calls)	40%
Breakdown of outgoing calls in per cent of total outgoing calls	
Operator, toll, information, etc.	15%
Calls to office A	25%
Calls to office B	20%
Calls to office C	15%
Calls to office D	10%
Calls to office E	8%
Calls to office F	7%

Breakdown of incoming calls—it will be assumed that incoming traffic breaks down with respect to source on the same basis as outgoing calls with respect to destination. No attempt will be made to engineer incoming trunk groups.

All calls require seven dialed digits except the one-digit "0" operator calls and the three-digit (X11) special service calls.

Division of originating traffic in accordance with major classes of service

Flat rate (individual, two and four-party)	70%
Message rate, no overtime charge (individual and two-party)	20%
Coin, with overtime charge	10%

On the basis of the given figures, the busy hour originating and terminating traffic load in CCS can be calculated. First, the number of calls in the various categories:

Total originating calls	11,500
Total good originating calls	10,700
Intraoffice calls (.60 x 10,700)	6,420*
Outgoing calls (.40 x 10,700)	4,280*
Incoming calls (same as outgoing)	4,280*
Partial dial calls	800**

Originating and terminating load:

Originating Register load: 11,500 x 13.5 x .01 =	1552	CCS
Intraoffice load: 6420 x 115 x .01 =	7400	CCS
Outgoing load: 4280 x 115 x .01 =	4930	CCS
Incoming load: 4280 x 115 x .01 =	4930	CCS
Partial dial load: 800 x 6 x .01 =	48	CCS
Total originating and terminating office load =	18860	CCS
Originating and terminating load per line: $\frac{18860}{7000}$ =	2.70	CCS

Engineering of Line Link and Trunk Link Frames

The line link frames are designed to accommodate from 290 to 690 lines per frame in steps of 100 lines. The generally accepted load capacity of a line link frame to give a satisfactory grade of service is 1200 CCS per busy hour. From this figure and the known load per line and number of lines, the number of lines per line link frame and the number of frames can be calculated.

Number of lines per frame: $\frac{1200}{2.70} = 445$

Number of frames: $\frac{7000}{445} = 15.7$

These figures indicate that 16 line link frames of 490-line capacity should be installed. This provides adequate spare equipment to care for any readjustments that may later prove necessary.

Since trunk link frames have twice the traffic capacity of line link frames, eight of them are required. These frame quantities specify a particular standard cabling arrangement on the junctor grouping frame for interconnecting line link and trunk link frames.

All line link frames can handle all classes of service up to a maximum of 30. It is generally advisable to distribute the lines in the various classes of

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*No account is taken of the approximately 10 per cent of calls that encounter busy lines.

**It is assumed that all of these are set up to tone trunks with a holding time of 6 seconds.

service over the frames in order to equalize traffic. Lines are assigned to classes of service in vertical file groups (groups of ten) by means of cross-connections on the frame. Separate classes of service must be assigned to lines not only in the major categories such as flat rate, coin, message rate, but also when there is differentiation in the rate or routing treatment.

PBX lines and lines associated with message registers require sleeve cross-connections from the line link frame. Provision for these connections is made at the factory on certain vertical files, and such lines should be assigned to these positions. The markers are arranged to give preference on originating calls to lines in one particular vertical group comprising 40 lines (the other ten line positions of this vertical group are reserved for no-test calls by an operator), and lines such as police, fire, and other emergency services should be placed in this group. Coin lines, also, are given this preferred location.

Engineering of Markers

At present, the required number of markers is based entirely upon the number of busy-hour originating calls. In the preparation of the Marker Table, shown on Figure 12-14, allowance has been made for all the variable factors, including terminating traffic, that affect marker capacity.

Since office X has a busy-hour originating call rate of 11,500, the table requires provision of nine markers. It is customary to provide one additional marker above the requirements since a marker may be out of service in the busy-hour for maintenance purposes. Therefore ten markers are required for the office. It should be noted now that a supplementary bay is required on all connector frames to take care of more than six markers. Provision of these supplementary bays will be assumed in later paragraphs.

Markers are arranged to handle either 10, 20, or 30 classes of service depending upon the requirements of the office. Associated with the class of service equipment are service relays whose contacts, in conjunction with the route relays, provide different charging or routing treatment for the various classes of service. This equipment is mounted on the Class-of-Service Bay (see Figure 12-4C) which contains the class circuits for four markers. The quantity and arrangement of all this equipment must be determined as part of the engineering job.

A separate route relay is, in general, required for each trunk group, including Originating Registers, to which originating calls may be set up. Certain standards have been established relating particular route relays with each type of trunk group, and these should be followed in engineering the office. In addition to specifying the number of route relays, it is necessary to determine the large number of cross-connections which must be made in order to relate codes, route relays, service class, trunk group location, out-signaling information, and the like, for the particular office. The route relays and the associated cross-connection fields are mounted on frames, shown on Figure 12-4B, individual to each marker.

NO. 5 CROSSBAR SYSTEM

MARKER TABLE

In this table allowance has been made for false starts on dial tone connections, for short period peaks within the busy hour and for peak hours within the year not reflected in peg counts.

This table is not applicable for use in offices used for tandem or toll tandem switching or where appreciable use is made either of marker pulse conversion or operator assistance trunks.

Markers for Traffic	Equivalent Manual Peg Count Originating Busy Hour Calls	Markers for Traffic	Equivalent Manual Peg Count Originating Busy Hour Calls
2 (Minimum)	2150	7	9400
3	3600	8	10,850
4	5050	9	12,300
5	6500	10	13,750
6	7950	11	15,200

Considerable latitude for judgment in the use of the tables exists in deciding how much overload should be assumed for a group of markers as an alternative to adding one more marker. To illustrate: If the table requirements are 3.9 markers, the provision of four for traffic is obvious; but if the requirements are a small fraction over 3.0 markers, say 3.1, the fraction may be disregarded or be translated into a whole marker, depending upon the engineer's judgment as to the conservativeness or liberality of his traffic estimate, the frequency and severity of traffic peaks in the office, and other factors, some of which are discussed in the following paragraphs.

A sufficient number of markers should, of course, be provided to insure adequate service during the first few days after cutover as well as to meet requirements at the end of the engineering period. If it appears that an extra marker is required for cutover only, careful consideration is, of course, given to possible means of avoiding its provision. The following are some of the factors that will materially influence the final decision as to its provision.

The firmness of the estimate of cutover stimulation. These estimates are usually based on the Company's experience in other similar communities. System experience shows that the stimulation varies from practically nothing in offices in cities that are largely dial already to as high as 40 per cent. in some suburban communities. It is assumed that originating registers will be provided on a basis that takes into account the cutover stimulation and any expected increase in holding time due to slow dialing so that lack of originating registers will not impose on additional load on he markers.

A second factor is the length of time which will elapse before the extra marker would be required for growth.

Another factor to be considered is the possibility of relying upon the maintenance marker to provide the added call carrying capacity needed at cutover. This question is, of course, to be decided entirely by the Plant and Engineering Departments.

Figure 12-14 No. 5 Crossbar System Marker Table

Finally, the connections for the trunk link frame test lead connector relays must be determined. For office sizes up to ten trunk link frames, one connector relay must be associated with each route relay to connect to the markers the test leads which indicate idle frames with idle trunks. These connector relays are grouped on bays shown on Figure 12-4D, one of which will mount the equipment for as many as six markers.

Engineering of Originating Registers and Register Connectors

The number of Originating Registers required is determined primarily by the calculated load in CCS. The traffic table relating load to number of registers takes into account factors which may not appear in the calculated load, such as false starts which seize a register momentarily, and longer seizures in which no dialing occurs. Since, for the office under consideration, the register load as determined on page 28 is 1552 CCS, the register table shown on Figure 12-15 specifies 72 registers. To this basic quantity must be added some number of registers, say 10 per cent or seven, to compensate for units out of service for trouble or maintenance reasons. This results in a total of 79 originating registers for office X.

The traffic capacity of each originating register marker connector is 1500 busy-hour calls. On the assumption that all originating calls require a marker seizure by the register, the number of connectors required is

$$\frac{11,500}{1500} = 7.67, \text{ or } 8$$

Ten registers would be assigned to each of seven connectors, and nine registers to one connector, to account for the 79 originating registers.

There are a number of options which may be specified for the originating registers. These include such items as the number of digits which may legitimately be dialed, the two-party test feature, coin lines on a coin or dial tone first basis, and the various specific classes of service.

Engineering of Trunks

Only two types of trunk circuits, intraoffice and outgoing interoffice will be considered in this paragraph. The engineering of the large number of miscellaneous trunks such as operator, toll, and tone trunks follows the same general procedure as will be outlined for the intraoffice type.

Several types of intraoffice trunks are available. Some are designed to function with originating lines of a particular class of service, and others with lines in any one of several service classes. Examples of trunk types are:

Flat rate only
Non-coin automatic message accounting
Coin without overtime
Coin with overtime
Flat rate and message rate without overtime
Message rate without overtime, and coin with overtime, and so forth.

NO. 5 CROSSBAR SYSTEM

ORIGINATING REGISTER TABLE

Registers	CCS	Registers	CCS
1	.036	51	1051
2	1.62	52	1073
3	6.88	53	1102
4	15.4	54	1123
5	26.6	55	1148
6	40.0	56	1174
7	54.7	57	1199
8	70.9	58	1224
9	88.2	59	1246
10	107	60	1271
11	126	61	1296
12	145	62	1321
13	166	63	1346
14	187	64	1372
15	208	65	1397
16	231	66	1422
17	253	67	1447
18	276	68	1472
19	299	69	1498
20	323	70	1523
21	346	71	1548
22	370	72	1573
23	392	73	1598
24	414	74	1624
25	436	75	1649
26	457	76	1674
27	479	77	1699
28	504	78	1724
29	526	79	1750
30	547	80	1775
31	572	81	1800
32	594	82	1825
33	619	83	1854
34	644	84	1876
35	666	85	1904
36	688	86	1930
37	713	87	1955
38	734	88	1980
39	760	89	2005
40	785	90	2034
41	806	91	2059
42	832	92	2084
43	857	93	2110
44	878	94	2135
45	904	95	2160
46	929	96	2185
47	954	97	2214
48	976	98	2239
49	1001	99	2264
50	1026	100	2290

For groups of more than 100 registers 22.9 CCS per register should be used.
Based on Table 1 for 1 to 21 registers.
Based on Table 10 beyond 21 registers, modified by a reduction of 23% in CCS to compensate for subscriber irregularities not reflected in Peg Count Calls.

Figure 12-15 No. 5 Crossbar System Originating Register Table

In some cases, particularly when lines in one class of service offer a large part of the traffic, it is desirable to specify single-type trunks for use by that class. In other cases, it is more economical to specify combined type trunks to serve several classes of lines. The decision involves careful consideration of trunk cost and relative quantities in either combined or single class trunk groups.

It was determined on page 28 that the intraoffice trunk load was 7400 CCS. This is divided among three classes of service as shown below.

Flat rate: 70% of 7400 = 5180 CCS
Message rate, no overtime: 20% of 7400 = 1480 CCS
Coin with overtime: 10% of 7400 = 740 CCS

An adequate grade of service for trunk groups of this type is provided when the probability of loss is ten calls in one thousand. The traffic table corresponding to this grade is shown on the two pages of Figure 12-16, and is headed Table 10. The CCS load for the flat-rate trunks exceeds the 100-trunk limit of Table 10 and cannot be read off directly. However, the traffic engineering practices in these circumstances suggest assuming a single-trunk capacity of 28 CCS. On this basis, the number of flat rate trunks required is

$$\frac{5180}{28} = 185$$

To this quantity must be added some number, say 10 per cent or 19, of extra trunks for maintenance purposes. This establishes a total of 204 flat rate trunks. Since the marker is capable of testing in one effective group a maximum of 20 trunks per trunk link frame (160 trunks for the eight frames of office X), the flat rate trunks must be divided into two so-called allotter groups approximately equal in size. Since the markers alternate their group choice on successive calls and immediately test in the second group if the first is all busy, there is no reduction of efficiency from splitting the group.

The message rate trunks, with a load of 1480 CCS, require 58 circuits according to Table 10 in Figure 12-16. This group, with six maintenance trunks added, totals 64. Table 10 also requires 33 coin trunks based on a load of 740 CCS. Four additional maintenance trunks raise the total of coin trunks to 36.

If the message rate and coin traffic is combined, the increased efficiency of a common group of trunks may justify use of combined type trunks instead of single type. In this case the combined load is 2220 CCS, which calls for 81 trunks. Maintenance trunks raise this quantity to 89, offering a saving of 11 trunks over two groups of single-type trunks. It will be assumed that the combined group is the more economical arrangement. Intraoffice trunk requirements for office X are, then:

Flat rate service: 204 flat rate trunks

Message rate, no overtime; and coin with overtime:
89 combined message rate without overtime and coin with overtime trunks

TRUNK CAPACITY TABLES
Hundred Call-Seconds and Per Cent.
Use at Various Service Levels for
Trunk Groups of 1 to 50

The Table Number Indicates the Number of Calls per 1000 Encountering All Trunks Busy

Trunks	Table 1		Table 5		Table 10		Table 20		Table 30		Table 40		Trunks
	CCS	% Usage	CCS	% Usage	CCS	% Usage	CCS	% Usage	CCS	% Usage	CCS	% Usage	
1	.1	.1	.2	.5	.4	1.0	.7	2.0	1.1	3.1	1.5	4.2	1
2	1.6	2.3	3.7	4.8	5.4	7.5	7.9	10.9	9.7	13.5	11.3	15.7	2
3	6.9	6.4	12.2	11.3	15.7	14.5	20.4	18.9	24.0	22.2	26.9	24.9	3
4	15.4	10.7	24.2	16.8	29.6	20.6	36.7	25.5	41.6	28.9	45.7	31.8	4
5	26.6	14.8	38.9	21.6	46.1	25.6	55.8	31.0	61.6	34.2	66.6	37.0	5
6	40.0	18.5	55.4	25.7	64.4	29.8	76.0	35.2	82.8	38.3	89.3	41.3	6
7	54.7	21.7	73.4	29.1	83.9	33.3	96.8	38.4	105	41.7	112	44.4	7
8	70.9	24.6	92.5	32.1	105	36.5	119	41.3	129	44.8	137	47.6	8
9	88.2	27.2	113	34.9	126	38.9	142	43.8	153	47.2	162	50.0	9
10	107	29.7	134	37.2	149	41.4	166	46.1	178	49.4	188	52.2	10
11	126	31.8	156	39.4	172	43.4	191	48.2	204	51.5	214	54.0	11
12	145	33.6	178	41.2	195	45.1	216	50.0	230	53.3	240	55.6	12
13	166	35.5	201	42.9	220	47.0	241	51.5	256	54.7	267	57.1	13
14	187	37.1	224	44.4	244	48.4	267	53.0	283	56.1	295	58.5	14
15	208	38.5	248	45.9	269	49.8	293	54.3	310	57.4	322	59.6	15
16	231	40.0	273	47.4	294	51.1	320	55.6	337	58.5	350	60.8	16
17	253	41.3	297	48.5	320	52.3	347	56.7	365	59.6	378	61.8	17
18	276	42.6	322	49.7	346	53.4	374	57.7	392	60.5	407	62.8	18
19	299	43.7	347	50.7	373	54.5	401	58.6	420	61.4	436	63.8	19
20	323	44.9	373	51.8	399	55.4	429	59.6	449	62.4	465	64.6	20
21	346	45.8	399	52.8	426	56.4	458	60.6	478	63.2	494	65.3	21
22	370	46.7	424	53.5	453	57.2	486	61.4	507	64.0	523	66.0	22
23	395	47.7	451	54.5	480	58.0	514	62.1	536	64.7	552	66.7	23
24	419	48.5	477	55.2	507	58.7	542	62.8	564	65.3	582	67.4	24
25	444	49.3	504	56.0	535	59.4	571	63.4	593	65.9	611	67.9	25
26	469	50.1	531	56.7	562	60.1	599	64.0	623	66.6	641	68.5	26
27	495	50.9	558	57.4	590	60.7	627	64.5	652	67.1	671	68.9	27
28	520	51.6	585	58.0	618	61.3	656	65.1	682	67.7	701	69.6	28
29	545	52.2	612	58.6	647	62.0	685	65.6	711	68.1	731	70.0	29
30	571	52.9	640	59.3	675	62.5	715	66.2	741	68.6	762	70.6	30
31	597	53.5	667	59.8	703	63.0	744	66.7	771	69.1	792	71.0	31
32	624	54.2	695	60.3	732	63.6	773	67.1	801	69.5	822	71.4	32
33	650	54.7	723	60.8	760	64.0	803	67.6	831	69.9	852	71.7	33
34	676	55.2	751	61.4	789	64.5	832	68.0	861	70.3	883	72.1	34
35	703	55.8	779	61.8	818	64.9	862	68.4	891	70.7	913	72.5	35
36	729	56.3	807	62.3	847	65.4	892	68.8	922	71.1	944	72.8	36
37	756	56.8	836	62.8	876	65.8	922	69.2	952	71.5	975	73.2	37
38	783	57.3	864	63.2	905	66.2	952	69.6	982	71.8	1006	73.5	38
39	810	57.7	892	63.5	935	66.6	982	69.9	1013	72.1	1037	73.9	39
40	837	58.1	921	64.0	964	66.9	1012	70.3	1043	72.4	1069	74.2	40
41	865	58.6	950	64.4	993	67.3	1042	70.6	1074	72.8	1099	74.4	41
42	892	59.0	979	64.7	1023	67.7	1072	70.9	1104	73.0	1130	74.7	42
43	919	59.4	1008	65.1	1052	68.0	1103	71.3	1135	73.3	1161	75.0	43
44	947	59.8	1036	65.4	1082	68.3	1133	71.5	1166	73.3	1192	75.3	44
45	975	60.2	1066	65.8	1112	68.6	1164	71.8	1197	73.9	1223	75.5	45
46	1003	60.6	1095	66.1	1142	69.0	1194	72.1	1228	74.2	1255	75.8	46
47	1030	60.9	1124	66.4	1171	69.2	1225	72.4	1259	74.4	1286	76.0	47
48	1058	61.2	1153	66.7	1201	69.5	1255	72.6	1291	74.7	1317	76.2	48
49	1086	61.6	1183	67.1	1231	69.8	1286	72.9	1322	74.9	1349	76.5	49
50	1115	61.9	1212	67.3	1261	70.1	1317	73.2	1353	75.2	1381	76.7	50

Figure 12-16 Trunk Capacity Table—Sheet 1 of 2 Sheets

TRUNK CAPACITY TABLES
Hundred Call-Seconds and Per Cent.
Use at Various Service Levels for
Trunk Groups of 51 to 100

The Table Number Indicates the Number of Calls per 1000 Encountering All Trunks Busy

Trunks	Table 1		Table 5		Table 10		Table 20		Table 30		Table 40		Trunks
	CCS	% Usage	CCS	% Usage	CCS	% Usage	CCS	% Usage	CCS	% Usage	CCS	% Usage	
51	1143	62.3	1241	67.6	1291	70.3	1348	73.4	1384	75.4	1412	76.9	51
52	1171	62.6	1271	67.9	1322	70.6	1378	73.6	1416	75.6	1444	77.1	52
53	1200	62.9	1301	68.2	1352	70.9	1410	73.9	1447	75.8	1475	77.3	53
54	1228	63.2	1330	68.4	1382	71.1	1441	74.1	1478	76.0	1507	77.5	54
55	1256	63.4	1360	68.7	1412	71.3	1472	74.3	1509	76.2	1539	77.7	55
56	1285	63.8	1390	68.9	1443	71.6	1503	74.6	1541	76.4	1571	77.9	56
57	1313	64.0	1419	69.2	1473	71.8	1534	74.8	1572	76.6	1602	78.1	57
58	1342	64.3	1449	69.4	1504	72.0	1565	74.9	1604	76.8	1634	78.3	58
59	1371	64.6	1479	69.6	1534	72.2	1596	75.1	1635	77.0	1666	78.4	59
60	1400	64.8	1509	69.9	1565	72.4	1627	75.3	1667	77.2	1698	78.6	60
61	1428	65.0	1539	70.1	1595	72.6	1659	75.5	1698	77.3	1730	78.8	61
62	1457	65.3	1570	70.3	1626	72.9	1690	75.7	1730	77.5	1762	78.9	62
63	1486	65.5	1599	70.5	1657	73.1	1722	75.9	1762	77.7	1794	79.1	63
64	1516	65.8	1630	70.7	1687	73.2	1752	76.1	1794	77.9	1826	79.3	64
65	1544	66.0	1660	70.9	1718	73.4	1784	76.3	1825	78.0	1858	79.4	65
66	1574	66.2	1690	71.1	1749	73.6	1816	76.4	1857	78.2	1890	79.6	66
67	1603	66.4	1721	71.3	1780	73.8	1847	76.6	1889	78.3	1922	79.7	67
68	1632	66.7	1751	71.5	1811	74.0	1878	76.7	1921	78.5	1955	79.9	68
69	1661	66.9	1781	71.7	1842	74.2	1910	76.9	1953	78.6	1987	80.0	69
70	1691	67.1	1812	71.9	1873	74.3	1941	77.0	1985	78.8	2019	80.1	70
71	1720	67.3	1842	72.1	1904	74.5	1973	77.2	2017	78.9	2051	80.3	71
72	1750	67.5	1873	72.3	1935	74.7	2004	77.3	2048	79.0	2084	80.4	72
73	1779	67.7	1903	72.4	1966	74.8	2036	77.5	2080	79.1	2116	80.5	73
74	1809	67.9	1934	72.6	1997	75.0	2067	77.6	2112	79.3	2148	80.6	74
75	1838	68.1	1965	72.8	2028	75.1	2099	77.8	2145	79.4	2181	80.8	75
76	1868	68.3	1995	72.9	2059	75.3	2130	77.9	2176	79.5	2213	80.9	76
77	1898	68.5	2026	73.1	2091	75.4	2162	78.0	2209	79.7	2245	81.0	77
78	1927	68.6	2057	73.3	2122	75.6	2194	78.1	2241	79.8	2278	81.1	78
79	1957	68.8	2088	73.4	2153	75.7	2226	78.3	2273	79.9	2310	81.2	79
80	1986	69.0	2118	73.5	2184	75.8	2258	78.4	2305	80.0	2343	81.3	80
81	2016	69.1	2149	73.7	2215	76.0	2290	78.5	2337	80.1	2375	81.4	81
82	2046	69.3	2180	73.9	2247	76.1	2322	78.7	2370	80.3	2408	81.6	82
83	2076	69.5	2211	74.0	2278	76.3	2354	78.8	2402	80.4	2440	81.7	83
84	2106	69.6	2242	74.1	2310	76.4	2386	78.9	2435	80.5	2473	81.8	84
85	2136	69.8	2273	74.3	2341	76.5	2418	79.0	2467	80.6	2506	81.9	85
86	2166	70.0	2304	74.4	2373	76.6	2450	79.1	2499	80.7	2538	82.0	86
87	2196	70.1	2335	74.6	2404	76.8	2482	79.3	2532	80.8	2571	82.1	87
88	2226	70.3	2366	74.7	2436	76.9	2514	79.4	2564	80.9	2604	82.2	88
89	2256	70.4	2397	74.8	2467	77.0	2546	79.5	2596	81.0	2636	82.3	89
90	2286	70.6	2428	74.9	2499	77.1	2578	79.6	2629	81.1	2669	82.4	90
91	2317	70.7	2459	75.1	2530	77.2	2611	79.7	2661	81.2	2702	82.5	91
92	2346	70.8	2490	75.2	2562	77.4	2643	79.8	2694	81.3	2735	82.6	92
93	2377	71.0	2521	75.3	2594	77.5	2674	79.9	2726	81.4	2767	82.6	93
94	2407	71.1	2553	75.4	2625	77.6	2706	80.0	2759	81.5	2800	82.7	94
95	2437	71.3	2584	75.6	2657	77.7	2739	80.1	2791	81.6	2833	82.8	95
96	2468	71.4	2615	75.7	2689	77.8	2771	80.2	2824	81.7	2865	82.9	96
97	2498	71.5	2646	75.8	2721	77.9	2803	80.3	2857	81.8	2898	83.0	97
98	2528	71.7	2678	75.9	2752	78.0	2836	80.4	2889	81.9	2931	83.1	98
99	2559	71.8	2709	76.0	2784	78.1	2868	80.5	2921	82.0	2964	83.2	99
100	2589	71.9	2740	76.1	2816	78.2	2900	80.6	2954	82.1	2996	83.2	100

Figure 12-16 Trunk Capacity Table—Sheet 2 of 2 Sheets

The engineering of outgoing interoffice trunks is handled on a somewhat different basis than intraoffice trunks when there is a possibility of utilizing alternate routes through the tandem office as shown on Figure 12-15. When this possibility exists, a set of traffic tables different from the ordinary trunk capacity tables are used. The alternate routing tables show, for different values of CCS load offered, the CCS load carried by each additional trunk as it is added to the direct group and the CCS load remaining for additional direct trunks or the alternate route. Three pages of the alternate routing tables are shown on Figure 12-17. As an example of the information in the table, if a total load of 900 CCS is offered, adding a 27th trunk to a group will increase the call-carrying capacity of the group by 19 CCS and leave 91 CCS to be carried by an alternate route. Adding one more trunk increases group capacity by only 16 CCS and leaves 75 CCS for the alternate route.

In engineering trunk groups of this kind, it is necessary to calculate the economic balance between the cost of direct and alternate route trunks for each terminating office. The balance can be ascertained as the minimum CCS load which the last trunk in a direct route must carry in order to be economical. The number of the last trunk which adds the minimum load determines the group size; the overflow CCS is placed in the tandem trunk pool. Although the value of the last trunk minimum load usually varies from office to office because of different interoffice separations, in the present case it will be assumed that on trunks to offices A, B, C, and D it is 25 CCS, and on trunks to offices E and F it is 35 CCS.

The total outgoing CCS load was determined on page 28 to be 4930 CCS, which, except for 15 per cent going to operators, and so forth, was divided among offices A through E. In the tabulation below, the division of traffic among the offices is shown together with the numbers of direct trunks and the tandem CCS obtained from the alternate routing tables. The values for office A can be checked against Figure 12-17.

	Per Cent Of Total	CCS Per Office	Direct Trunks	Overflow CCS To Tandem
Operator calls, etc.	15	740		
Calls to A	25	1231	32	210
Calls to B	20	987	25	194
Calls to C	15	740	18	174
Calls to D	10	493	11	157
Calls to E	8	395	—	395
Calls to F	7	345	—	345
Total Tandem CCS				1475 CCS

On the basis that 1475 CCS is the total tandem load, the trunk capacity tables of Figure 12-16 indicate requirements for 58 tandem trunks. To all these trunk groups should be added extra trunks for maintenance purposes. It will be assumed that combined service type trunks are used in all groups.

ALTERNATE ROUTING TRUNK TABLES

Hundred Call-Seconds Carried by and Overflowing
From Each Trunk Shown in Column Headings

CCS Offered	Trunk Number 21 Car.	21 Ofl.	22 Car.	22 Ofl.	23 Car.	23 Ofl.	24 Car.	24 Ofl.	25 Car.	25 Ofl.	26 Car.	26 Ofl.	CCS Offered
810	24	155	22	133	21	112	19	93	17	76	15	61	810
820	24	163	23	140	22	118	19	99	18	81	16	65	820
830	25	170	23	147	22	125	20	105	18	87	17	70	830
840	25	178	24	154	22	132	21	111	19	92	17	75	840
850	26	185	24	161	23	138	21	117	19	98	18	80	850
860	26	193	25	168	23	145	21	124	20	104	18	86	860
870	26	201	25	176	24	152	22	130	20	110	18	92	870
880	26	209	25	184	24	160	23	137	21	116	19	97	880
890	27	217	26	191	24	167	23	144	21	123	19	104	890
900	27	225	26	199	25	174	23	151	22	129	19	110	900
910	27	233	26	207	25	182	24	158	22	136	20	116	910
920	28	241	26	215	25	190	24	166	23	143	21	122	920
930	28	249	26	223	26	197	24	173	23	150	22	128	930
940	28	258	27	231	26	205	25	180	23	157	22	135	940
950	29	266	27	239	26	213	25	188	24	164	22	142	950
960	29	274	27	247	26	221	25	195	24	171	23	148	960
970	29	283	27	256	27	229	25	203	25	178	23	155	970
980	29	292	28	264	27	237	26	211	25	186	24	162	980
990	29	301	28	273	28	245	26	219	25	194	24	170	990
1000	29	309	28	281	28	253	26	227	26	201	24	177	1000
1010	29	318	28	289	28	261	26	235	26	209	25	184	1010
1020	29	327	28	298	28	270	27	243	26	217	25	192	1020
1030	29	336	29	307	29	278	27	251	26	225	26	199	1030
1040	30	344	29	315	29	286	27	259	26	233	26	207	1040
1050	30	353	29	324	29	295	28	267	26	241	26	215	1050
1060	30	362	29	333	29	304	28	276	27	249	26	223	1060
1070	30	371	30	341	29	312	28	284	27	257	27	230	1070
1080	30	380	30	350	29	321	28	293	28	265	27	238	1080
1090			30	359	30	329	28	301	28	273	27	246	1090
1100			30	368	30	338	28	310	28	282	27	255	1100
1110			30	377	30	347	29	318	28	290	27	263	1110
1120			30	386	30	356	29	327	29	298	27	271	1120
1130			30	395	30	365	29	336	29	307	28	279	1130
1140					30	374	30	344	29	315	28	287	1140
1150					30	383	30	353	29	324	28	296	1150
1160					30	392	30	362	29	333	28	304	1160
1170					30	401	30	371	29	342	28	313	1170
1180					30	410	30	380	30	350	29	321	1180
1190					30	419	30	389	30	359	29	330	1190
1200									30	367	29	338	1200
1210									30	376	29	347	1210
1220									30	385	29	356	1220
1230									30	394	30	364	1230
1240									30	403	30	373	1240
1250											30	382	1250
1260											30	391	1260
1270											30	400	1270
1280											30	409	1280
1290											30	418	1290

Figure 12-17 Alternate Routing Trunk Tables—Sheet 1 of 3 Sheets

ALTERNATE ROUTING TRUNK TABLES

Hundred Call-Seconds Carried by and Overflowing
From Each Trunk Shown in Column Headings

CCS Offered	Trunk Number 27 Car.	27 Ofl.	28 Car.	28 Ofl.	29 Car.	29 Ofl.	30 Car.	30 Ofl.	31 Car.	31 Ofl.	32 Car.	32 Ofl.	CCS Offered
810	13	48	11	37	9	28	8	20	6	14	4	10	810
820	13	52	12	40	10	30	8	22	6	16	5	11	820
830	14	56	12	44	10	34	9	25	7	18	5	13	830
840	15	60	13	47	11	36	9	27	7	20	6	14	840
850	15	65	13	52	12	40	10	30	8	22	6	16	850
860	16	70	14	56	12	44	10	34	9	25	7	18	860
870	17	75	15	60	13	47	11	36	9	28	7	20	870
880	17	80	15	65	14	51	11	40	10	30	8	22	880
890	18	86	16	70	14	56	12	44	10	34	9	25	890
900	19	91	16	75	15	60	13	47	11	36	9	27	900
910	19	97	17	80	15	65	14	51	11	40	9	31	910
920	19	103	18	85	16	69	14	55	12	43	10	33	920
930	19	109	19	90	16	74	14	60	13	47	11	37	930
940	20	115	19	96	17	79	15	64	13	51	11	40	940
950	21	121	19	102	18	84	15	69	14	55	12	43	950
960	21	127	19	108	19	89	16	73	14	59	12	47	960
970	21	134	20	114	19	95	16	79	15	64	13	51	970
980	22	140	20	120	19	101	17	84	15	69	14	55	980
990	23	147	21	126	19	107	18	89	16	73	14	59	990
1000	23	154	21	133	20	113	19	94	16	78	14	64	1000
1010	23	161	22	139	20	119	19	100	17	83	15	68	1010
1020	24	168	22	146	21	125	19	106	18	88	16	72	1020
1030	24	175	23	152	21	131	19	112	18	94	16	78	1030
1040	24	183	23	160	22	138	20	118	19	99	17	82	1040
1050	25	190	24	166	22	144	20	124	19	105	17	88	1050
1060	25	198	24	174	23	151	21	130	19	111	18	93	1060
1070	25	205	24	181	23	158	21	137	20	117	19	98	1070
1080	25	213	25	188	23	165	22	143	20	123	19	104	1080
1090	26	220	25	195	23	172	22	150	21	129	19	110	1090
1100	27	228	25	203	24	179	23	156	21	135	19	116	1100
1110	27	236	25	210	24	186	23	163	21	142	20	122	1110
1120	27	244	25	218	24	194	23	171	22	149	21	128	1120
1130	27	252	26	226	25	201	24	177	22	155	21	134	1130
1140	27	260	26	234	25	209	24	185	23	162	22	140	1140
1150	28	268	26	242	26	216	24	192	23	169	22	147	1150
1160	28	276	26	250	26	224	24	199	23	176	22	154	1160
1170	28	285	27	258	26	232	24	207	24	183	23	160	1170
1180	28	293	27	266	27	239	25	214	24	190	23	167	1180
1190	28	302	28	274	27	247	25	222	25	197	23	174	1190
1200	28	310	28	282	27	255	25	230	25	205	24	181	1200
1210	28	318	28	290	27	263	26	237	25	212	24	188	1210
1220	28	327	28	299	28	271	26	245	25	220	25	195	1220
1230	29	335	28	307	28	279	26	253	25	228	25	205	1230
1240	29	344	28	316	28	288	27	261	26	235	25	210	1240
1250	29	353	29	324	28	296	27	269	26	243	25	218	1250
1260	29	361	29	332	28	304	27	277	26	251	25	225	1260
1270	29	370	29	341	28	313	28	285	27	258	25	232	1270
1280	30	379	29	350	29	321	28	293	27	266	26	240	1280
1290	30	388	29	359	29	330	28	302	28	274	26	248	1290
1300	30	397	30	367	29	338	28	310	28	282	26	256	1300

Figure 12-17 Alternate Routing Trunk Tables—Sheet 2 of 3 Sheets

ALTERNATE ROUTING TRUNK TABLES

Hundred Call-Seconds Carried by and Overflowing
From Each Trunk Shown in Column Headings

CCS Offered	Trunk Number 33 Car.	33 Ofl.	34 Car.	34 Ofl.	35 Car.	35 Ofl.	36 Car.	36 Ofl.	37 Car.	37 Ofl.	38 Car.	38 Ofl.	CCS Offered
820	4	7											820
830	4	9											830
840	4	10											840
850	4	11	4	7									850
860	5	13	4	9									860
870	6	14	4	10									870
880	6	16	4	12	4	8							880
890	7	18	5	13	4	9							890
900	7	20	5	15	4	11							900
910	8	23	6	17	5	12	4	8					910
920	8	25	7	18	5	13	4	9					920
930	9	28	7	21	6	15	4	11					930
940	9	31	8	23	6	17	5	12	4	8			940
950	10	33	8	25	7	18	5	13	4	9			950
960	10	37	9	28	7	21	6	15	4	11			960
970	11	40	9	31	8	23	6	17	5	12	4	8	970
980	12	43	10	33	8	25	6	19	5	14	4	10	980
990	12	47	10	37	9	28	7	21	6	15	4	11	990
1000	13	51	11	40	9	31	8	23	6	17	5	12	1000
1010	13	55	12	43	10	33	8	25	6	19	5	14	1010
1020	14	58	12	46	10	36	8	28	7	21	6	15	1020
1030	15	63	13	50	10	40	9	31	8	23	6	17	1030
1040	15	67	13	54	11	43	10	33	8	25	6	19	1040
1050	16	72	14	58	12	46	10	36	8	28	7	21	1050
1060	16	77	14	63	13	50	11	39	9	30	7	23	1060
1070	16	82	15	67	13	54	11	43	10	33	8	25	1070
1080	17	87	15	72	14	58	12	46	10	36	8	28	1080
1090	18	92	16	76	14	62	12	50	11	39	9	30	1090
1100	18	98	17	81	15	66	12	54	11	43	10	33	1100
1110	19	103	17	86	15	71	13	58	12	46	10	36	1110
1120	19	109	18	91	15	76	14	62	12	50	11	39	1120
1130	20	114	18	96	16	80	14	66	13	53	11	42	1130
1140	20	120	18	102	17	85	15	70	13	57	11	46	1140
1150	20	127	19	108	17	91	16	75	14	61	12	49	1150
1160	21	133	19	114	18	96	16	80	14	66	13	53	1160
1170	21	139	20	119	18	101	16	85	15	70	13	57	1170
1180	22	145	20	125	18	107	17	90	15	75	14	61	1180
1190	22	152	21	131	19	112	17	95	16	79	14	65	1190
1200	22	159	21	138	20	118	18	100	16	84	15	69	1200
1210	23	165	21	144	20	124	18	106	17	89	15	74	1210
1220	23	172	21	151	21	130	19	111	17	94	16	78	1220
1230	24	179	22	157	21	136	19	117	18	99	16	83	1230
1240	24	186	22	164	21	143	20	123	18	105	17	88	1240
1250	24	194	23	171	22	149	20	129	19	110	17	93	1250
1260	24	201	23	178	22	156	21	135	19	116	17	99	1260
1270	24	208	23	185	23	162	21	141	19	122	18	104	1270
1280	25	215	23	192	23	169	21	148	20	128	19	109	1280
1290	25	223	24	199	23	176	22	154	20	134	19	115	1290
1300	25	231	25	206	23	183	22	161	21	140	19	121	1300

Figure 12-17 Alternate Routing Trunk Tables—Sheet 3 of 3 Sheets

After the size of all trunk groups has been determined, including the incoming and miscellaneous groups that have not been discussed, the location of the trunk appearances on the trunk link frames must be worked out. Standard procedures for assigning trunks to horizontal levels on the frames have been established and must be followed. In addition, the cross-connections for the individual trunk test leads, the frame grouped test leads, outgoing sender and incoming register link frames, and so forth, must be determined.

Engineering of Outgoing Senders, Connectors and Links

If offices A, B, C, and D are the step-by-step type and the tandem office is equipped for receiving multifrequency pulsing, two types of outgoing senders are required for office X; namely, dial pulse senders for controlling the step-by-step offices, and multifrequency senders for transmiting information to the tandem office. The number of calls utilizing each type of sender can be calculated in this case by determining from the CCS values the proportions of total outgoing calls to the two varieties of office. From the table in the preceding section, 740 CCS constitutes the operator traffic and 1475 CCS the tandem traffic. Therefore step-by-step or dial pulse traffic is the total outgoing traffic miuus these two quantities, or

$$4930 - (740 + 1475) = 2715 \text{ CCS}$$

The proportion of outgoing traffic on dial pulse trunks is

$$\frac{2715}{4930} = .55$$

The proportion of outgoing traffic on multifrequency trunks is

$$\frac{1475}{4930} = .30.$$

Since the total number of out calls is 4280 (from page 28) the number of calls using each type of trunk is

$.55 \times 4280 = 2355$ calls on dial pulse trunks
$.30 \times 4280 = 1285$ calls on multifrequency trunks

The holding times for outgoing senders is obtained from the traffic table shown on Figure 12-18. The load calculations, recalling that the dial pulsing offices require four digits, and the multifrequency offices seven digits, are as follows:

$2355 \times 5.25 \times .01 = 123.5$ CCS for DP out senders
$1285 \times 2.50 \times .01 = 32.2$ CCS for MF out senders

Table 10 (Figure 12-16) of the trunk capacity table is adequate for outgoing senders. Therefore, the sender requirements are nine DP senders plus one for maintenance, or a total of ten, and five MF senders plus one for maintenance, or a total of six.

There are a number of options available in the outgoing senders which must be specified. A number of digits up to 11 can be registered in the sender, depending upon requirements, and certain of them can be deleted or not by the sender when out-pulsing. Also, arbitrary digits may have to be substituted or added to the outgoing code. Dial pulse senders can be wired to pulse at either 10 or 20 pulses per second or both, as determined by the type of terminating office. In this case, 10 pulses per second is necessary to control the step-by-step offices. Finally, certain options are necessary when the office is arranged for Automatic Message Accounting.

The outgoing sender connectors, providing access between markers and senders, have a capacity of 3000 busy-hour calls. Since these connectors, which can accommodate all types of senders on the same unit, are always provided in pairs, one pair is sufficient for office X. The 16 senders should be distributed equally over the two connectors, with half of each sender type on each connector.

The outgoing sender links, providing access between senders and outgoing trunks, are equipped with ten 200-point crossbar switches on a frame. Senders are

NO. 5 CROSSBAR SYSTEM

OUTGOING SENDER HOLDING TIMES (IN SECONDS)

	Type of Sender (4-Digit Calls - See Note)			
Type of Terminating Office	Multi-Frequency	Revertive	Dial	Call Indicator
Step-by-step			5.25	
Panel		4.50	3.20	
#1 Crossbar	2.10	3.55	3.90	
#5 Crossbar	2.05	3.55	3.20	
Manual			5.25	6.10
*Panel Sender Tandem				4.80
*Crossbar Tandem	2.50		5.70	
*#4 Toll Crossbar	2.50			
Note: Add for each additional digit	.13		1.15 (Low Speed) .60 (High Speed)	

* Holding times quoted for Tandem and #4 Toll Crossbar are for 7 digits.

Figure 12-18 No. 5 Crossbar System—Outgoing Sender Holding Times

wired to the switch horizontals and trunks to the verticals. The senders are limited to groups of ten, but two groups can be placed on each switch by splitting the horizontal multiple. A further restriction is that each switch can connect only to trunks on a single trunk link frame. The trunk, frame, and sender requirements of office X permit the use of one sender link frame with the two sender groups associated on each switch with the appropriate type of trunk. For circuit reasons each sender group must be divided between the upper and lower five horizontal levels of the switches in the same manner as they were divided between sender connectors.

Engineering of Incoming Registers, Connectors and Links

The engineering of incoming registers depends upon incoming traffic which has not been calculated in detail. However, it can be assumed in the present case that, percentage wise, incoming traffic breaks down in the same manner as outgoing traffic. Since the calls from offices A, B, C, and D total 70 per cent of the incoming traffic and there is no alternate routing available from step-by-step offices, the number of calls from these offices requiring a dial pulse incoming register is .70 x 4280 = 3000. It will be assumed that the remainder of the calls, 1280, come from tandem, also on a dial pulse basis. Calls from step-by-step offices are subscriber dialed at 10 pulses per second, while those from tandem are circuit-pulsed at 20 pulses per second.

Register holding times are obtained from the traffic table of Figure 12-19. The load calculations are as follows:

$$\text{CCS from A, B, C, D} = 3000 \times 6.7 \times .01 = 201$$
$$\text{CCS from tandem} = 1280 \times 3.4 \times .01 = \frac{43.5}{244.5}$$

It is recommended that when the registers must accept subscriber dialing, Table 1 (Figure 12-16) be used in determining register quantities in order to minimize delay in associating a register with a trunk. On this basis, 17 registers are required. Since the register link imposes a limit of ten registers in a single group, the register must be subgrouped. Dividing the total CCS in half requires two subgroups of eleven each, which is still too many for a link group. If the incoming load from the local offices is separated from the total and divided in half (100.5 CCS), Table 1 calls for ten registers in each of these groups. This leaves no room for maintenance registers, but on the basis of the liberal engineering ten registers may be considered satisfactory. If a register is out of service for maintenance reasons, the grade of service will drop to a probability of loss of five calls out of a thousand. The tandem group, on the basis that the registers can give a start-dialing signal, can be engineered from Table 10 (43.5 CCS) with the result that five are required plus one for maintenance to give a total of six.

Several options are available as component parts of the incoming registers. The registers can handle up to eleven digits (six or more are required only when the office is used for tandem or toll switching) and the particular number must be

specified. If the registers serve a single terminating office unit, or if separate trunk groups are used for each unit of a combined terminating office, four digits only are required. However, if common trunks to a combined terminating office are employed, a fifth directing digit is necessary.

The registers may be equipped to furnish dial tone, a start-dialing signal, or neither, as conditions dictate. In the present case, dialing over the trunks from offices A, B, C, and D is by subscribers and no tone or signal should be provided. However, it will be assumed that these trunks are wired to register links equipped for by-link operation in order to speed-up the association of a register with a requesting trunk. The register group which is utilized by the trunk group from tandem, on the other hand, should be wired to give a start-dialing signal and by-link operation is not required.

Three incoming register link frames, each of which can accommodate up to ten registers and 100 trunks, are therefore necessary to handle the incoming traffic of office X. The trunks from offices A, B, C, and D should be divided between two

NO. 5 CROSSBAR SYSTEM

INCOMING REGISTER HOLDING TIMES (IN SECONDS)

	Calls to	
	Single Unit	Paired Units Via Combined Trunk Group
Multi-Frequency Pulsing Registers		
From #5 Crossbar	2.00	2.00
From Key Pulsing Switchboards	5.30	5.90
Two Digit Office Code + 4 Numerals	-	7.20*
Three Digit Office Code + 4 Numerals	-	7.80*
From #4 Toll (call pulsed into #4 Via 10 Button Key Set)	3.30	3.90
*Calls via a single trunk group.		
Revertive Pulsing Registers		
From #5 Crossbar, Panel, Panel Sender Tandem and Crossbar Tandem	3.40	3.40
From #1 Crossbar	4.55	4.55
Dial Pulsing Registers - 20 Pulses per Second		
From #5 Crossbar	3.55	4.15
From Dialing Switchboards	5.80	6.80
From Panel Sender Tandem and Crossbar Tandem	3.40	4.00
Dial Pulsing Registers - 10 Pulses per Second		
From Step-by-Step	6.70	-
From Dialing Switchboards	7.30	8.60
From Panel Sender Tandem and Crossbar Tandem	5.60	6.75

Figure 12-19 No. 5 Crossbar System—Incoming Register Holding Times

link frames wired for by-link operation, each frame with one group of ten incoming registers arranged for subscriber dialing. The tandem trunks should be placed on the third frame associated with the remaining group of six registers.

An incoming register marker connector has a traffic capacity of 2500 busy-hour calls. Since the number of incoming calls is 4280, the number of connectors required is

$$\frac{4280}{2500} = 1.71 \text{ or } 2$$

Thirteen registers should be placed in each connector, the registers associated with each link being divided between the two connectors.

Engineering of the Number Groups

Since each number group frame handles 1000 directory numbers, and office X comprises upward of 9000 numbers, ten number groups are required. For number group cross-connection purposes, the line link frame location, ringing type, and PBX status of each working main station must be predetermined and coordinated.

Optional features for the number group frames deal primarily with the number and size of PBX hunting groups and free terminating lines. Provision may also be made for taking busy or overflow records on a limited number of lines or PBX groups. One number group connector is required for each number group.

12.5 CONCLUSION

The preceding paragraphs have presented in some detail the process of engineering a No. 5 Crossbar central office to meet a particular set of requirements. The purpose has been tc develop an appreciation of the engineering procedure. To this end the basic requirements were purposely kept simple and only the major equipment units were treated. It will be understood that in an actual engineering job the traffic data is in a much less concrete form, more classes of service must be considered, the prevailing and changing rate treatment of the several service classes has to be satisfied, and a large number of minor circuits such as special trunks must be accounted for. In addition, the major central office elements of power and maintenance equipment have not been discussed at all. Responsibility for many of these factors in central office engineering lies not only in the traffic, but in the plant and, to some extent, the commercial divisions of telephone companies' organizations.

However, it is obvious that the engineering aspects of telephone switching systems must be actively in mind at the very inception of a new switching system, and must be kept in mind during the design period by everyone contributing to the project. No matter how brilliant in a technical sense a switching concept may be, it can never reach the installation stage if the systems based upon it can not meet the standards imposed by traffic engineering requirements.

12.6 REFERENCES

1. Traffic Engineering Practices, Division D—Dial Equipment; Sections 1 and 8 in particular.

2. Traffic Engineering Practices—General Considerations—Training of Traffic Engineers—Division A, Section 2.

CHAPTER 13

BASIC RELAY CONTROL PATHS

13.1 GENERAL

A combination of relay contacts and windings is referred to as a relay circuit. In order to facilitate design or analysis of such circuits, the relays whose interconnections or functions are closely related are usually grouped together on a schematic representation. These groups are then considered as separate relay circuits. Within circuits, complicated arrangements of contacts may control relays, but these complicated arrangements can be reduced generally to a few, basic types of relay control paths. This chapter describes such basic paths, and gives the more important reasons for preferring one over the other in switching circuit applications.

13.2 TERMINOLOGY AND SYMBOLS

Before describing basic relay control paths, a brief outline of some of the relay circuit terms will be given, together with their schematic representations. Throughout these chapters, the word contact will refer to a pair of mating conductors which are opened or closed by electromagnetic-mechanical means. A contact which closes when its relay operates is called a make (front) contact; one which opens when its relay operates, a break (back) contact. These are shown schematically in Figures 13-1A and 13-1B, together with their associated relay windings.

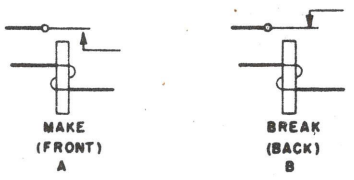


Figure 13-1 Single Contacts

Makes and breaks are often combined to save relay springs or to insure a definite sequence of path opening or closing. Examples of these are shown in Figure 13-2. The break-make, or transfer, opens path ab before closing ac, so that b and c are not connected during relay operation. The make-break, or continuity transfer, is used where a is to be connected to c before it is opened from b. Preliminary makes are used where a must be closed to b before any other contacts operate. In general, circuit designs requiring spring combinations with specified time sequences are avoided when economically possible since they are likely to require more maintenance than simpler combinations.

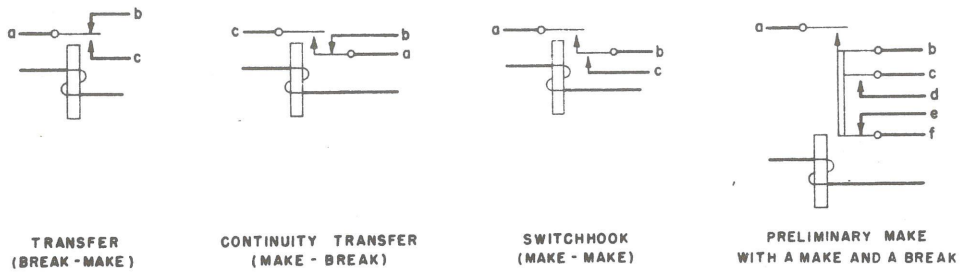


Figure 13-2 Combined Contacts

On schematic diagrams, relay contacts and controlling windings are usually grouped together as in Figure 13-3. Contacts are shown over or under the winding, corresponding to the physical construction of the actual relay used. The dot on the core symbol of the winding generally indicates the inner end of the winding. When the relay has a particular operating feature, that feature is indicated by the proper initials on the core symbol for the relay winding. Some of the more common initials are AC for alternating current, D for differential, FO for fast operate, MG for marginal, P for polar, SA for slow acting, and SR for slow release.

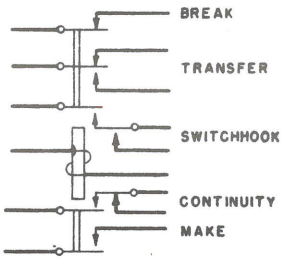


Figure 13-3 Relay With Spring Combination

When a circuit is being designed, on the other hand, it is often convenient to draw contacts and windings, unassociated, wherever convenient on the circuit diagram. Each contact and winding is identified by the corresponding relay designation as in Figure 13-4. Here a make contact on relay (F) and a break contact on relay (G) control relay (X). In this chapter, diagrams will be simplified by considering any contact arrangement, such as that in Figure 13-4, as a network "A" which will be open or closed depending on the component relay operations. This is shown schematically in Figure 13-5A. It is important to note that a contact network can have only two values-opened or closed.

13.3 OPERATING PATHS

Direct Operation

Figure 13-5A shows the simplest and most common relay control path. Relay (X) is under direct control of contact network A; when A is closed (X) is energized; when A is open (X) is de-energized. Figures

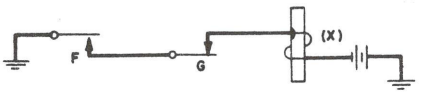


Figure 13-4 Simplified Circuit Sketch

13-5A and 13-5B are the same theoretically, but Figure 13-5A is generally preferred in practice since false grounds on the contact network will not blow a fuse or damage equipment. The arrangement of Figure 13-5B is sometimes desirable, however, when other requirements of a circuit are considered. Note that there will always be a time delay between path closure and relay operation while the magnetic field is being built up and the moving parts of the relay are in transit. A similar, but not necessarily equal, delay will exist between the opening of the path and the release of the relay.

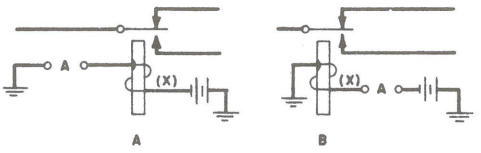


Figure 13-5 Direct Circuit Operation

Shunt Operation

In some cases it may be desired to operate a relay when a path opens. The circuit of Figure 13-6 does this by using a shunt path. When A is open, (X) is operated; when A is closed (X) is released.

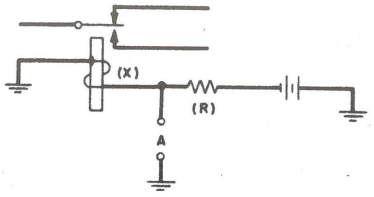


Figure 13-6 Shunt Operation

This arrangement has several disadvantages. In relay circuit design much effort is spent to keep a circuit economical and reliable. The resistor shown in Figure 13-6 is necessary to limit current through the shunting path but will add to the expense of the circuit. Also the current drain through the shunt path performs no useful work. In addition, the relay will be slow to release, which may be either an advantage or disadvantage. The reason for the slow release is that the magnetic field in the relay core does not collapse quickly. The field strength is dependent on current in the winding which, instead of being interrupted quickly, is allowed to decay exponentially through the shunt path.

13.4 LOCK-UP

In the previous control paths, the relay controlled had no part in its own operation. In a "locking" circuit a relay affects its own control path. Thus in Figure 13-7 the only path which can operate relay (X) is through network A. To release (X) however, it is necessary that paths through both A and B are open. Relay (X) is said to have "locked-up" to B.

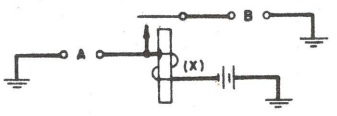


Figure 13-7 Lock-up

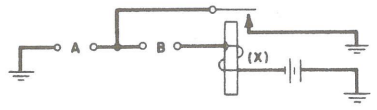


Figure 13-8 Variation of Basic Lock-up

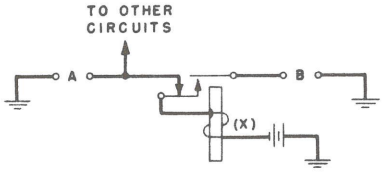


Figure 13-9 Continuity Lock-up

Figure 13-8 shows a similar locking circuit where A and B control in a slightly different manner. Another method of lock-up using a continuity is shown in Figure 13-9. It is evident that in this arrangement B must always be closed before A, or the act of (X) operating will break its operating path and release itself. Relay (X) will then buzz until B is closed, locking it up. Once (X) is locked up under control of B, A is free to control other paths without being affected by the ground on the winding of (X). Care must be taken that A is never closed when B is opened and that the "bunching" of the continuity contacts during operation and release produces no undesirable results. Other examples of lock-up paths are shown in Figure 13-10. Note that the control paths have different effects in the different circuits.

13.5 LOCK-DOWN

The lock-down is a scheme whereby a relay enters into its own control to keep itself from being operated by one path until another path has opened. As seen in the two arrangements in Figure 13-11, network A cannot operate relay (X) unless network B is open. Once (X) has been operated by A, however, B may open and close without releasing (X). This circuit requires a current limiting resistor and will drain current while the relay is shunted down. Acting time of the relay is

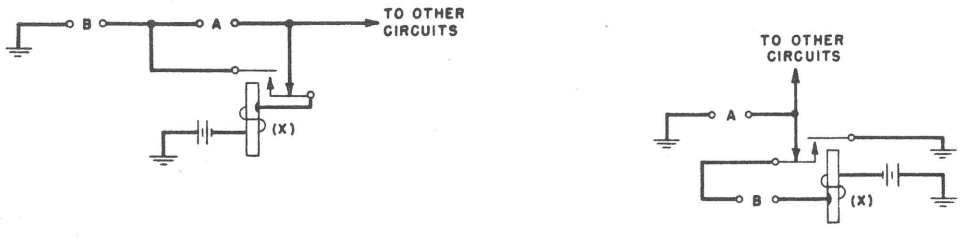


Figure 13-10 Variations of Continuity Lock-up



Figure 13-11 Lock-down

affected slightly by addition of the current limiting resistor; the shunt locking path, however, does not change this acting time.

13.6 SUMMARY OF THE FOUR BASIC CONTROL PATHS

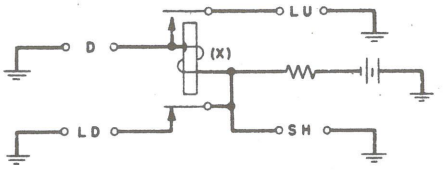


Figure 13-12 Basic Control Paths

Four basic control paths have been described so far. Figure 13-12 shows all of these applied to one relay. The paths are the direct D, shunt SH, lock-up LU, and lock-down LD. Analysis will show the inter-relationships between paths. For example the relay can never operate if D is open, or SH is closed, or LD is closed; SH can always release the relay; LD is without control after the relay has operated; and so forth. In circuit design it is often necessary to transfer a control function from one path to one or more of the other paths by proper contact configurations.

13.7 RELAYS WITH SPECIAL CHARACTERISTICS

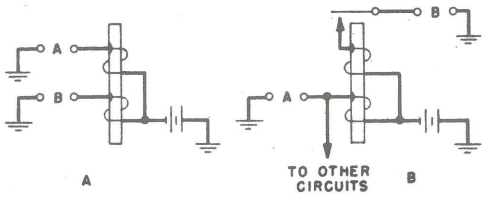


Figure 13-13 Use of Multiwound Relays

The preceding paragraphs have dealt with the basic ways of controlling a single-winding, general purpose relay. Often situations arise within a switching circuit that can be met more economically by relays with special characteristics than by relays controlled only by the paths described above. In addition, a restrictive design condition, such as a limited number of leads available for control, can sometimes be met only by use of relays with special characteristics. The rest of this chapter deals with the control of such relays.

13.8 MULTI-WOUND RELAYS

The most common use of a relay with several operating windings is to permit two or more operating paths of this relay to be isolated. A simple case is shown in Figure 13-13A. Either or both paths will operate relay (X) without shunting or otherwise interfering with each other. This scheme can be used to isolate completely an operating path from a locking path without the strict time sequence required of a continuity lock-up. This is shown in Figure 13-13B. Figure 13-14 shows another use for multi-winding relays in determining whether or not one or more of several paths are closed.

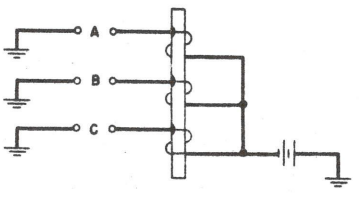


Figure 13-14 Check Circuit Using Multiwound Relay

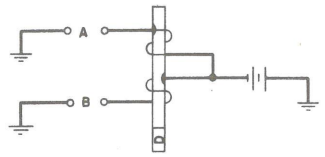


Figure 13-15 Differential Wound Relay

13.9 DIFFERENTIAL RELAYS

In a differential relay two windings are used in opposition in such a manner that when both are energized the net flux through the core is insufficient to operate the relay. As connected in Figure 13-15, A or B alone can operate relay (X), but if neither or both are closed, relay (X) is released. A common use for an arrangement of this kind is to give indication if two circuits such as A and B do not always open and close at the same time.

13.10 MARGINAL RELAYS

A marginal relay is one that will not operate on currents below a definite value through its winding but will operate with currents over this value. It is often used in arrangements such as Figure 13-16 where, in connection with a sensitive series relay, it can detect two conditions over a single lead. The sensitive relay operates on current below the non-operate current of the marginal relay. Thus A alone closed operates (S), but resistance R keeps the current too low to operate (MG). B closed operates both (S) and (MG).

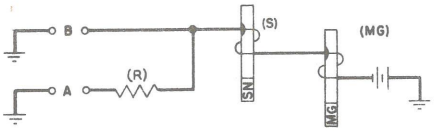


Figure 13-16 Operation of Marginal Relay

Theoretically a number of marginal relays could be used in series, operating successively as the current was increased in steps. However, variations in apparatus, adjustments, heating, battery voltage, and so forth, make close margins hard to meet; practical circuits are seldom found having more than one marginal condition.

13.11 POLAR RELAYS

Polar relays have two characteristics which make them valuable in switching and control circuits. First they react to current direction; second they are quite sensitive and capable of operating at high speed. The spring combination of the most used type of polar relay is limited to a maximum of a single transfer, and, unless biasing springs or windings are provided, there is no assurance which side, if either, of the transfer will be closed when the winding is de-energized.

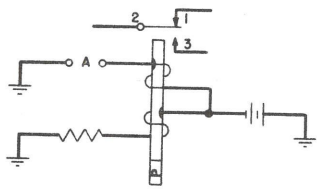


Figure 13-17 Polar Relay With Biasing Winding

Because of their sensitivity, polar relays are often used as marginal or sensitive relays to meet critical circuit conditions. An arrangement is shown in Figure 13-17 where the relay has two windings, one of which is used for biasing. The

biasing winding is poled to oppose the operating winding, and when energized alone, it holds the armature against contact No. 1. When the current in the operating winding exceeds that of the biasing windings by a small amount, the armature will operate to contact No. 3.

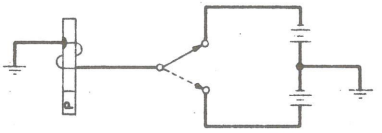


Figure 13-18 Polar Relay Control

When the relay is used for its polar characteristics, some means of reversing the flux must be provided. Figure 13-18 shows an easy way of doing this, but a battery with the negative side grounded is not always available in a telephone central office. Two voltages of different amplitude but same polarity as in Figure 13-19 achieve the same result. The source of lower voltage might be a resistance voltage divider.

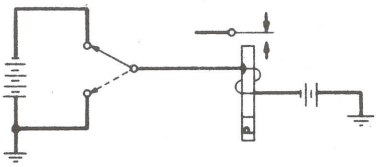


Figure 13-19 Polar Relay Control

13.12 SLOW-ACTING RELAYS

Although slow-acting relays do not utilize control paths other than those already discussed, they add a deliberate factor of time to the operation or release of a relay. A relay can be made either slow-operate or slow-release or both by the proper use of copper sleeves, shunted windings, condenser timing, or special construction; an example of a slow release by shunting was described in paragraph 13.3. Slow action may be desired for either of the following two reasons:

1. To produce or measure definite time intervals.
2. To reduce the number of circuit relays or contacts.

A combined example would be an all-relay circuit to flash a lamp at a rate to be easily followed by the human eye. Such a relay circuit can be designed using either a large number of normal speed relays or a small number of slow-acting relays. At times, the use of slow-acting relays is aimed not at slowing the circuit operation, although this may be an incidental result, but at increasing the reliability of a circuit detail.

Circuits involving slow-acting relays in the latter application will be discussed in a subsequent chapter, but for the present two examples will serve to indicate what such relays do. In Figure 13-20, control of relay (X) is to be transferred from contact network A to contact network B by the operation of relay (Y) which has only one transfer. If A and B are both closed, (X) is not to release during the transfer

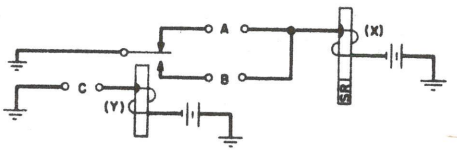


Figure 13-20 Use of Slow Release Relay

time of contacts on (Y). Making (X) slow release enables it to hold over the open interval. Figure 13-21 shows an example of a circuit using a slow-operate relay. In this circuit, for reasons not discussed, the continuity transfer on relay (Y) is required in order that when paths through contact networks A and B are closed, with relay (X) operated, the operation of relay (Y) will not momentarily open ground on the output lead. One of the other operations of the circuit, however, involves the operation of (Y) when path B is closed and path A is open with relay (X) released. If (X) is not to operate during this operation of (Y), some means of preventing its operation must be provided during the short interval in which ground from network B is applied to its winding through the bunched contacts on relay (Y). This type of false operation can be insured against by making the operate time of (X) longer than the bunching time of the continuity transfer on (Y).

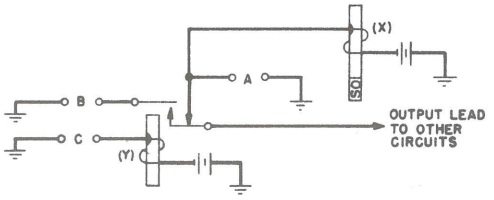


Figure 13-21 Use of Slow-Operate Relay

CHAPTER 14

RELAY CONTACT NETWORK CONFIGURATIONS—THE INTERCONNECTIONS OF CONTACTS TO SATISFY REQUIRED CONDITIONS

14.1 GENERAL

A relay contact network is a configuration of a number of individual contacts jointly controlling a circuit path. There are two general types of contact networks; two-terminal networks with a single input and single output terminal, and multi- or n- terminal networks. The sequence of operation of the individual contacts in the network may or may not be of importance, depending upon the application of the network. In this chapter only problems concerned with the configuration of contact networks are considered, without regard to sequence of operation. The network manipulations and simplifications discussed are of the most elementary variety. The problem of systematic network rearrangement is taken up in much greater detail in Chapter 15.

14.2 LOGIC OF CONTACT NETWORKS

The requirements which a contact network must fulfill may be formulated by stating those conditions under which the network will be open and those under which it will be closed. An analysis of the statement from the standpoint of logical validity is equivalent to an investigation of the network configuration itself. Thus, the tools and methods of logic underlie the analysis and solution of network problems.

Any two-terminal contact network can be considered to be a two-valued device. At any given instant it presents either an open (infinite impedance) or closed (zero impedance) path to electric current. Thus, the network can be represented by a single contact which is open or closed under conditions identical to those imposed on the network. Because the network, like the contact, can only be either open or closed, it is similar to a proposition in logic which is either true or false depending upon the truth or falsity of the various conditions of the proposition. For example, a proposition which is true only if conditions A and B are both true, corresponds to a network which is closed only if conditions A and B both obtain.

Each condition upon which the proposition relies corresponds to an individual contact in the network. The design of a contact network to perform a certain function under given conditions is an exercise in logic of synthesizing a complete

proposition from individual true or false statements. Moreover, the arrangement of the individual contacts in the network is similar to the relation of the various statements whose truth or falsity make the proposition true. If the synthesis of the proposition is not completely sound, the corresponding contact network will not function in the required manner. This similarity between networks and propositions in logic will be more fully brought out in succeeding sections.

14.3 "AND-OR" AND SERIES-PARALLEL RELATIONSHIPS

The most basic of all two-terminal networks are the simple series and simple parallel circuits shown in Figures 14-1 and 14-2. The network of Figure 14-1 is closed, and relay (R) operates only when both A and B are closed, whereas in Figure 14-2 the circuit is closed if A or B (or both) are closed. Figure 14-1 represents a proposition which is true only when both conditions A and B are true. The word "true," then, is equivalent to a closed path. If only one of the two conditions is true, the proposition is not true, and the circuit in Figure 14-1 would not be closed.

A proposition which is true if condition A or B is true is represented by Figure 14-2. It becomes evident that the conjunction "or" is equivalent to a parallel contact arrangement and "and" to a series contact arrangement. For example, consider the circuit shown in Figure 14-3. Relay (R) operates if A and (B or C) are closed. The equivalent statement in logic would be: "The proposition is true if conditions A and (B or C) are true." Similarly, in Figure 14-4 the circuit (or proposition) is closed (true) if A or (B and C) are closed (true). It is obvious that for more complicated circuits the punctuation of the statement might become highly complicated. However, it is possible, for any series-parallel network, to describe completely the conditions for circuit closure, indicating parallel combinations by "or" and series combinations by "and."

It should be noted that in the phrase "A or B," the two components are not inherently mutually exclusive. The network in Figure 14-2 is closed if A or B or both are closed.

Rather than stating a set of requirements in terms of open and closed contacts, it may be more convenient to state it in terms of relays operated and released. If a circuit is to be closed when a relay is operated, a make-contact is indicated; if the closure results from the release of a relay, the condition requires a break-contact. The relay circuit in Figure 14-5 is equivalent to the network in Figure 14-4 since the operating path for relay (R) is closed when relay (A), or relays (B) and (C) are operated. Another representation is shown in Figure 14-6 where relay (R) operates when relay (A) is operated, or when (B) is released and (C) is operated.

14.4 THE NEGATIVE RELATION

In logic, the "negative" of a proposition is a proposition which is false for those conditions, and only those conditions, for which the original proposition is true. The original proposition and its negative are, thus, mutually exclusive.

Similarly, the relation between a contact network and its negative is that one is closed when the other is open. It follows that, if network A is the negative of network B, B is also the negative of A. The most elementary example of a contact network and its negative is a make- and a break- contact on the same relay. When a circuit through one contact is closed the other is always open.*

It is often possible to determine the negative of a particular network by inspecting the statement of conditions for closure for that network.

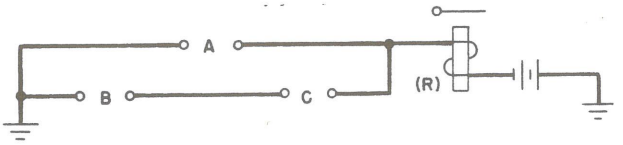


Figure 14-4 Relay (R) Operates for A, or B and C, Closed

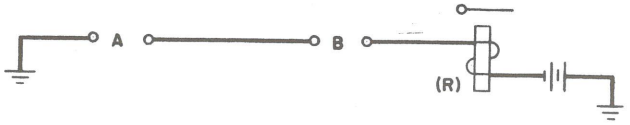


Figure 14-1 Relay (R) Operates for A and B Closed

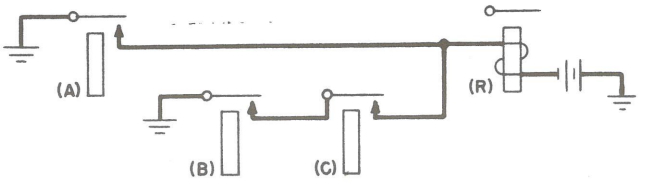


Figure 14-5 Relay (R) Operates for (A), or (B) and (C), Operated

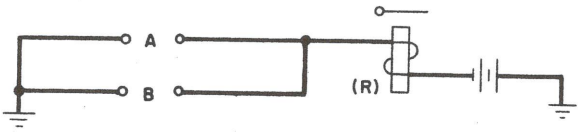


Figure 14-2 Relay (R) Operates for A or B Closed

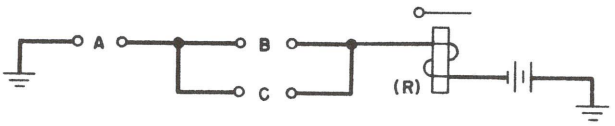


Figure 14-3 Relay (R) Operates for A, and B or C, Closed

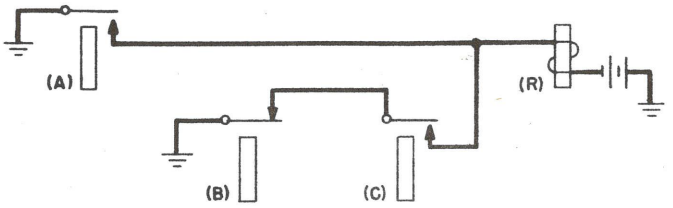


Figure 14-6 Relay (R) Operates for (A) Operated, or (B) Released and (C) Operated

*This, of course, is not necessarily true with commercial relays. During the acting time of these relays one contact may close before or after another opens.

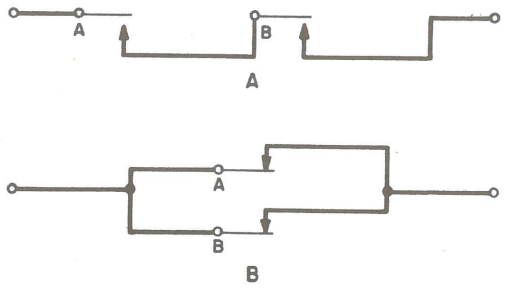


Figure 14-7 A Simple Network and Its Negative

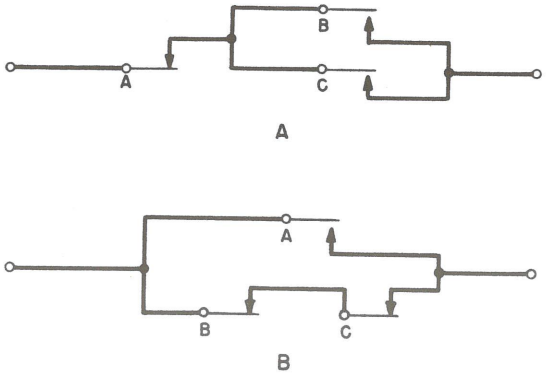


Figure 14-8 Another Network and Its Negative

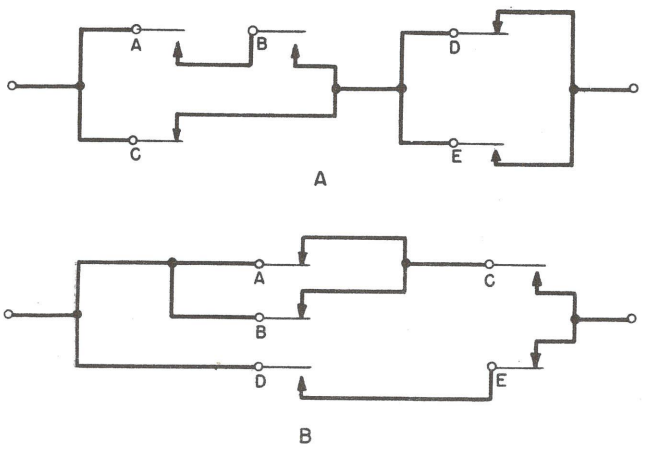


Figure 14-9 A More Elaborate Example of a Network and Negative

The circuit in Figure 14-7A is closed only when relays (A) and (B) are both operated. The negative of this network would then be one which is open only when relays (A) and (B) are both operated, and closed when (A) or (B) are released. In this final phrase, the "or" suggests parallel contacts, and the fact that the relays are released to close a circuit suggests that the contacts be breaks. The circuit is shown in Figure 14-7B. A second example is that of Figure 14-8A where relay (A) must be released and either (B) or (C) operated to close the network path. Brief consideration indicates that the circuit in Figure 14-8B is the desired negative.

From examination of the above networks and their negatives, it appears that to replace a network by its negative it is only necessary to substitute for each contact in the network its negative and to place these negatives in a network in which series and parallel connections have been interchanged. In actuality, this method of obtaining negatives holds for any two-terminal network consisting of only series and parallel connections*. A somewhat more complicated network and its negative illustrating the method are shown in Figure 14-9.

14.5 BASIC SIMPLIFICATIONS IN TWO-TERMINAL NETWORK DESIGN

After a two-terminal contact network has been designed for closure under given combinations of relays operated and released, it is

*The proof justifying this method will be indicated in Chapter 15.

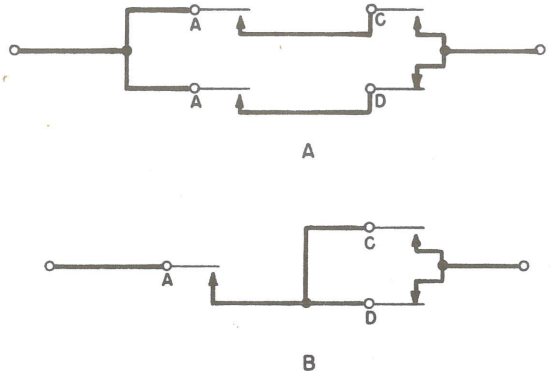


Figure 14-10 Combining Contacts

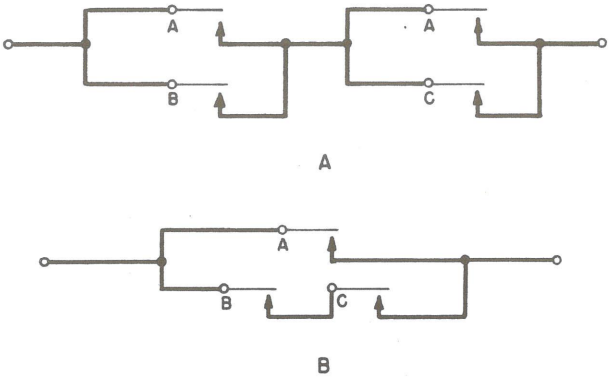


Figure 14-11 A Second Example of Combining Contacts

often possible to simplify the network by combining certain contacts and, perhaps, omitting others. First inspection often indicates simplifications which may be made at once. In the network of Figure 14-10A the circuit is closed if relays (A) and (C) are operated, or if relay (A) is operated and (D) is released. A simplified statement of the same conditions would be: "relay (A) operated, and (C) operated or (D) released." The network in Figure 14-10B, then, is equivalent to that of Figure 14-10A. A very similar example appears in Figure 14-11. Here it is again possible to combine the two make-contacts on relay (A) into a single make.

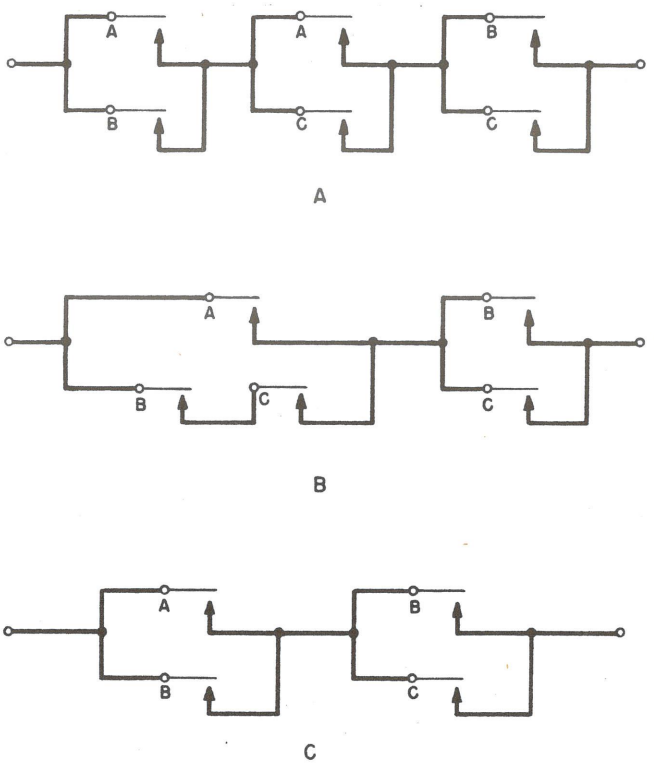


Figure 14-12 Network Simplification Illustrating an Invalid Step

Often it is possible to combine make- or break- contacts if they are on the same relay and if they have a common terminal. When this is done, it is well to check that the final network contains all those paths and only those paths that appear in the original network. Figure 14-12A shows a network, and Figure 14-12B, a simplified equivalent to that network. An attempt to simplify the network of Figure 14-12B might indicate combining the two makes on relay (C), resulting in the circuit of Figure 14-12C. This last manipulation, however, cannot be justified since a path not inherent in the original circuit is present in Figure 14-12C.

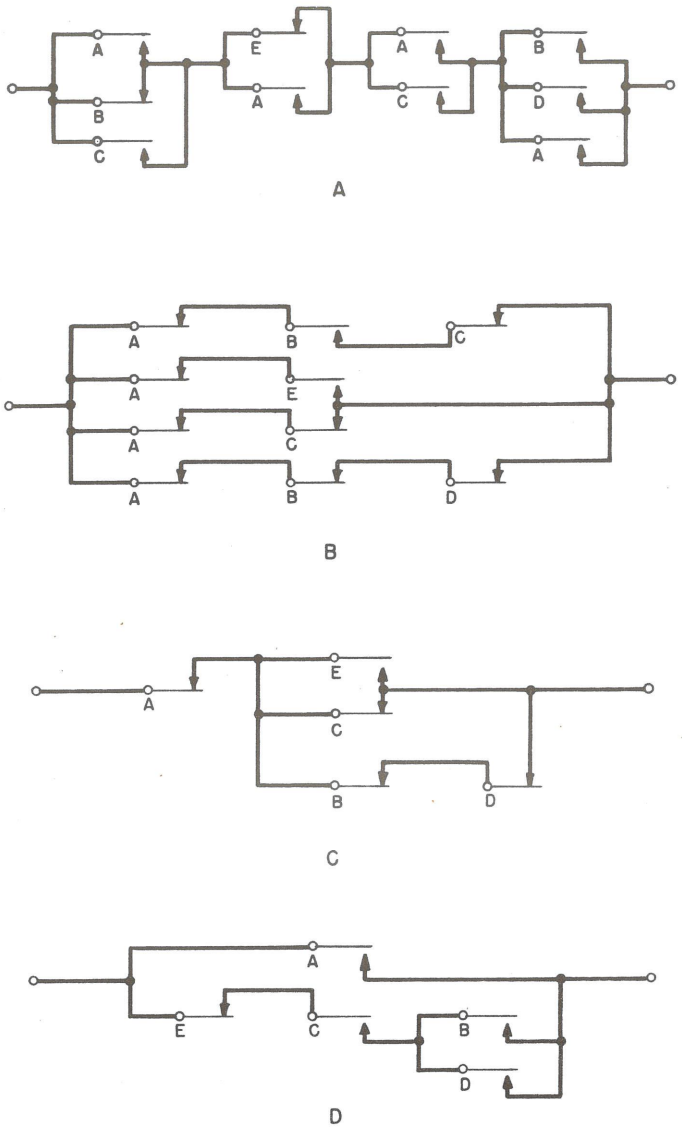


Figure 14-13 Simplification Employing Negative of Network

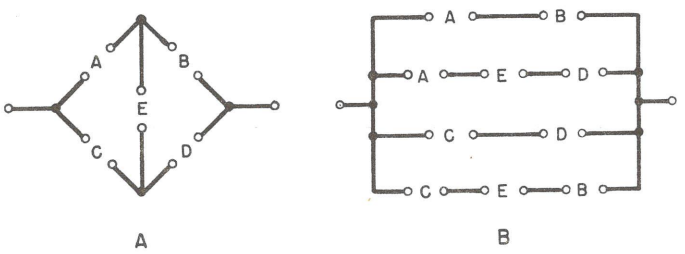


Figure 14-14 Basic Bridge Network and Its Series-Parallel Equivalent

(The network of Figure 14-12C is closed when B alone is closed, which is not true of Figure 14-12A).

Another method of simplification involves deriving the negative of the network, simplifying the negative, and finally taking the negative of this simplified circuit. By definition, the negative of the negative of a network is exactly equivalent to that network. To illustrate, the negative of the network in Figure 14-13A is determined by inspection. This negative circuit, shown in Figure 14-13B, is simplified by inspection to give the network of Figure 14-13C. Observe that the uppermost branch in Figure 14-13B is unnecessary since it is paralleled by series breaks on relays (A) and (C). Then, the negative of this simplification is drawn as in Figure 14-13D. Examination of Figure 14-13D shows that it contains all those paths contained in the circuit of Figure 14-13A and no others.

14.6 BRIDGE-TYPE NETWORKS

Not all two-terminal networks are composed of only series and parallel elements. Sometimes a circuit arrangement will include cross-connecting paths between parallel paths of series elements. Such networks are referred to as bridge-type networks.

The fundamental bridge-type network, shown in Figure 14-14A, is conveniently analyzed by tracing all possible paths between input and output terminals. These paths indicate all the conditions for

closure for the network and may be sketched as in Figure 14-14B. Any bridge-type network may be transformed into a series-parallel arrangement by this process of investigating all paths. The number of paths increases with the complexity of the bridge design. For example, the bridge in Figure 14-15 has thirteen possible paths between input and output terminals.

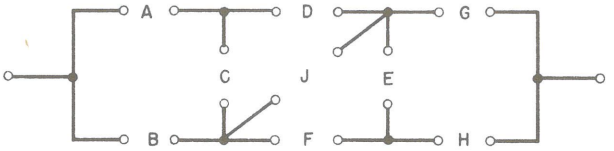


Figure 14-15 A More Complicated Bridge-Type Network

It is evident that the bridge circuit may afford some economy in number of contacts. Thus, such a network may be basically superior to its series-parallel equivalent. However, not every series-parallel arrangement has an equivalent bridge and, moreover, the equivalent bridge may be very difficult to derive. Also, because of the multiplicity of paths, circuit tracing and trouble shooting may be difficult. The use of a series-parallel network is often preferable if the cost of additional contacts is balanced by increased ease of maintenance.

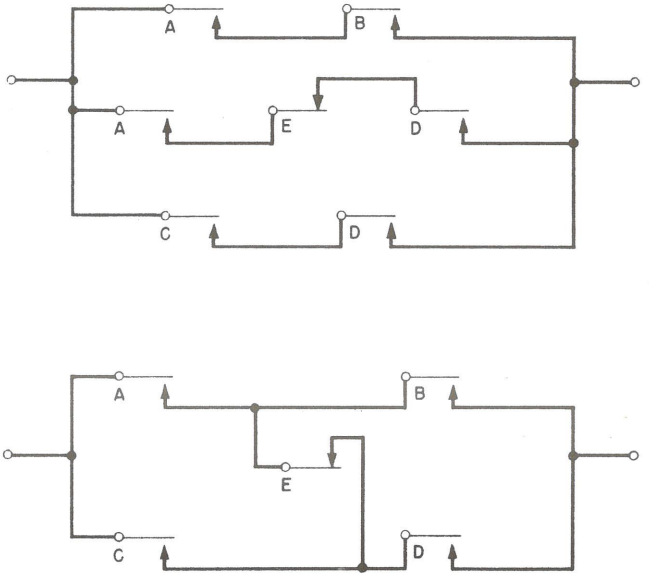


Figure 14-16 Series-Parallel Network and Non-Equivalent Bridge

Contact network simplification may, if the designer is not on guard, lead to a bridge-type circuit which is not exactly equivalent to the original network. An illustration of such inappropriate simplification is shown in Figure 14-16. Although the bridge network of this figure contains all the paths present in the original network, it also is closed for the combination of relay (B) and (C) operated and (E) released, a path not existent in the unsimplified circuit. Of course, the bridge network might be an acceptable equivalent if such a condition never exists.

14.7 MULTI-TERMINAL NETWORKS

The most common form of n- or multi-terminal network is that of a single input which may be connected through the network to two or more of several outputs.

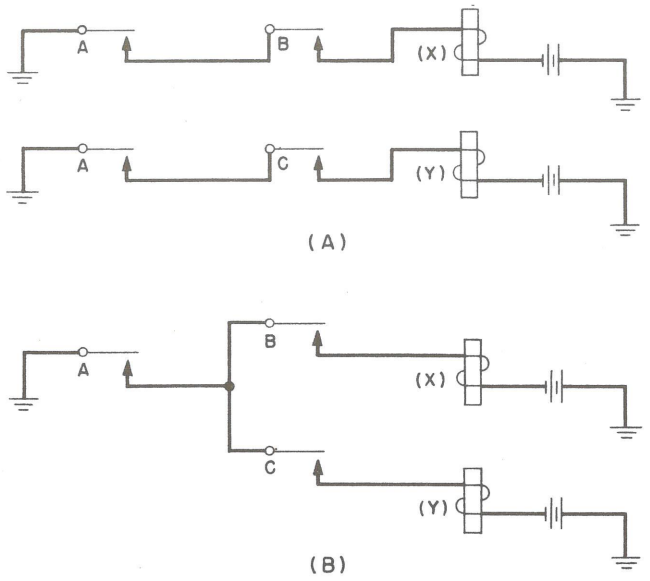


Figure 14-17 A Three-Terminal Network Reduced From Two Two-Terminal Networks

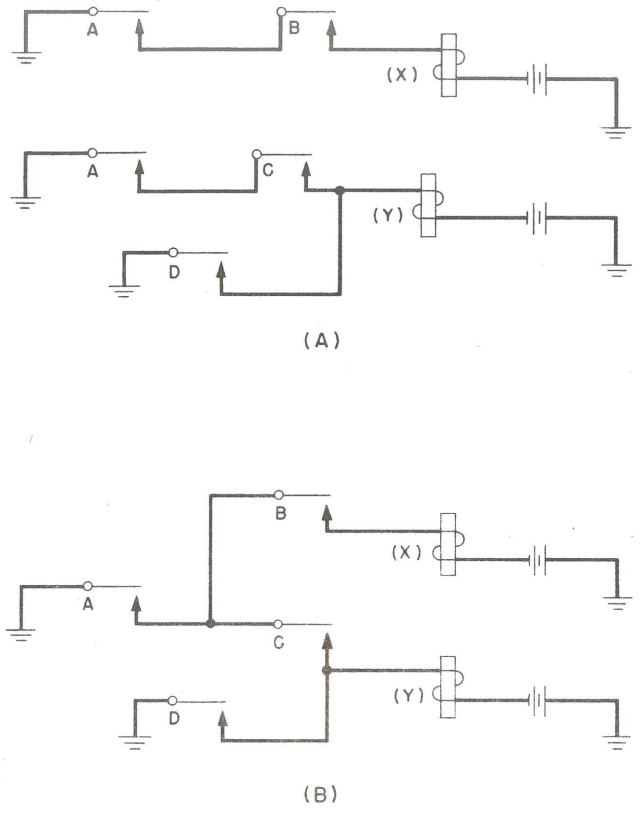


Figure 14-18 A Reduction of a Two-Terminal Network With a Sneak-Path Introduced

The design of such a network may be carried out as the design of several inter-related two-terminal networks. An elementary case is illustrated by Figure 14-17 where two make-contacts on relay (A) are combined into a single make. The resulting circuit is a three-terminal network, one terminal connected to ground and the other two to relay windings. However, care must be exercised in combining contacts to avoid sneak-paths between outputs. Such a sneak condition is shown in Figure 14-18B, and consists of path (B + C + D) which does not exist in the unsimplified network of Figure 14-18A.

It should be noted in the example in Figure 14-17B that if relays (B) and (C) are operated, the windings of relays (X) and (Y) are tied together, a situation which cannot occur in the circuit of Figure 14-17A. Whether this situation is undesirable depends upon the requirements for the circuit and possible conditions at the network terminals. For example, the addition of a holding contact on relay (X), as in Figure 14-19 would permit a sneak-path through the make-contacts on relays (C) and (B) to hold relay (Y) operated after relay (A) released. The effect of the sneak-path is to add a second condition for the operation of relay (Y): relays (B), and (C), and (X) operated; whereas the original operating path for (Y) was through operated relays (A) and (C).

14.8 TRANSFER-CONTACT NETWORKS

If, in a network, two paths pass through contacts on the same relay, one through a make- and the

second through a break-contact, these paths can never be closed at the same time—assuming no contact stagger. Paths exhibiting this characteristic are said to be "disjunctive." By network manipulation it may be possible to arrange the make and break contacts so that each has a terminal connected to a common junction point; under this condition a transfer contact may be substituted for the make and break. Such a substitution is shown in Figure 14-20. The outputs of the network connected to the windings of relays (X) and (Y) are disjunctive: the windings are completely isolated from one another at all times.

While a make- and break-contact on a relay, and the corresponding transfer combinations are both inherently disjunctive devices, the transfer combination is often preferable since it employs one less spring than the make and break arrangement. By its nature the transfer insures that only one of two paths can be closed at a given time. Thus it can be used to insure disjunctivity between paths or outputs.

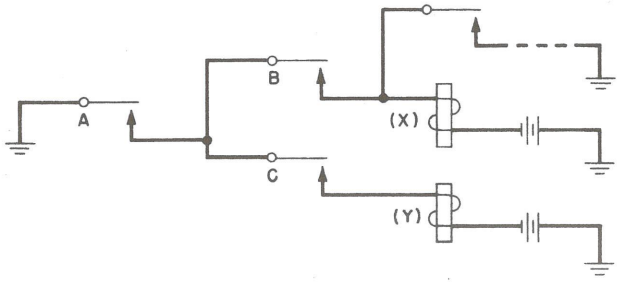


Figure 14-19 A Possible "Back-Up" Situation

Often it is not immediately recognizable that a transfer combination can be employed. In Figure 14-21 the make- and break-contacts on relay (A) have been replaced by a transfer. Here, the transfer arrangement is probably preferable since definite sequence between make and break on (A) is established and, as a result, there can be no momentary undesirable path in the circuit due to contact stagger on relay (A), if the make closes before the break opens.

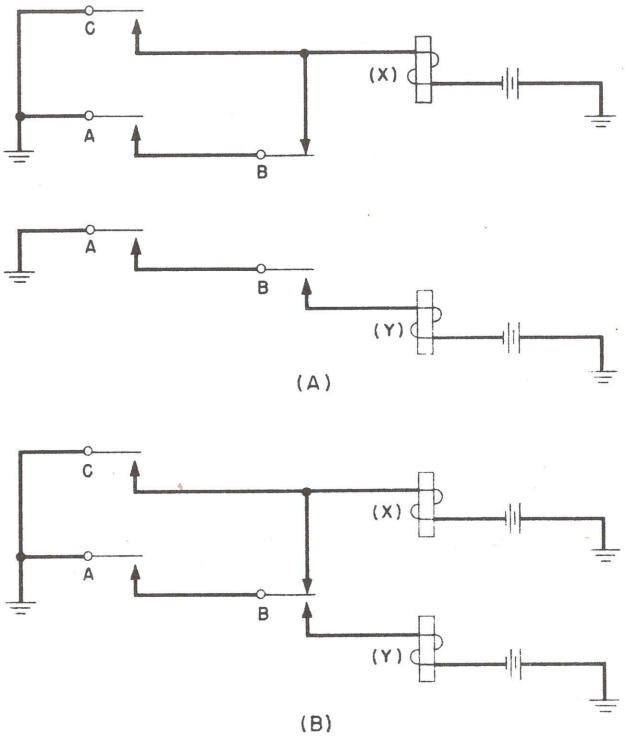


Figure 14-20 The Transfer-Contact Used to Isolate Outputs

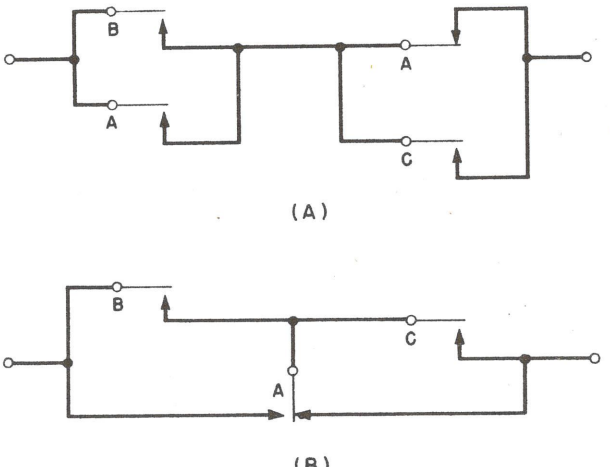


Figure 14-21 Example of a Transfer-Contact Used to Replace a Make and a Break-Contact

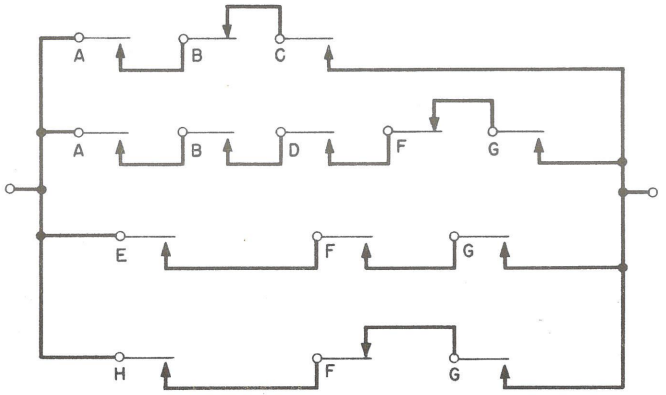
A more elaborate example of network manipulation is shown in Figure 14-22 It is evident from this illustration that the disjunctive character of the transfer allows simplifications which, at first glance, seem invalid.

14.9 TREE-TYPE CIRCUITS

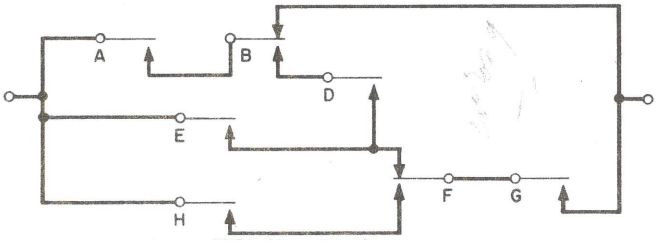
A "tree" is a particular type of multi-terminal network in which the single input may be connected to any one of m outputs according to the combination in which the relays actuating the network contacts are operated. The circuit of a four-relay tree is drawn in Figure 14-24. There are sixteen outputs, each output corresponding to one of the sixteen possible combinations in which four relays may be operated*. Only one output can be connected to the input at a time and, because of the transfer-contact combinations, the outputs are completely isolated under any condition. As well as being disjunctive, each path from input to an output in a true tree must pass through a contact on each controlling relay once and only once.

Because of the triangular symmetry of the tree, there is a definite relationship between the number of controlling relays, the number of outputs, the maximum number of transfers on one relay, and the total number of transfers in the tree. The table in Figure 14-23 below indicates this relationship. No proof is given but inspection will show that such a proof could easily be formulated.

A tree may not always be fully developed. For example, if outputs for operated relay combinations B, or BD, or BC, or BCD are not desired, two transfers on (D), one on (C) and the make half of a transfer on (B) can be eliminated.



(A)



(B)

Figure 14-22 More Elaborate Network Simplification

Number of relays in tree = n

Possible relay combinations = output terminals = $m = 2^n$

Maximum number of transfers on one relay = $m/2 = 2^{(n-1)}$

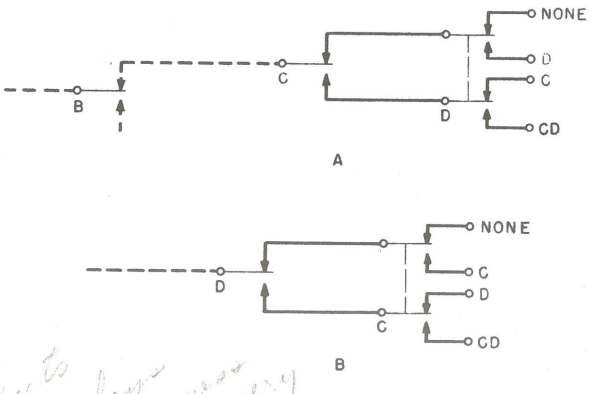
Total number of transfers in tree = $m-1 = 2^n-1$

Figure 14-23 Table of Quantities Involved in Fully Developed Trees

*One of the possible combinations is that the four relays are all released.

An obvious disadvantage of the tree circuit, as shown in Figure 14-24, is the very unequal distribution of the spring load on the relays. It is possible to obtain a more uniform loading on all the relays except the first by rearranging the circuit. Unfortunately, there is no method of rearrangement which will place more load on the first relay (the relay with the single transfer combination) without greatly increasing the total number of springs in the circuit.

In approaching the problem of rearranging the tree circuit for relay load equalization, note that the circuit is composed of branches or minor trees. For example, the branches of the four-relay tree may be regarded as two three-relay trees or as four two-relay trees. Any of these minor trees may be manipulated without affecting the operation of the complete tree. To illustrate, consider the uppermost of the four minor trees on relays (C) and (D), as shown in Figure 14-25A. The two transfers on (D) may be placed on



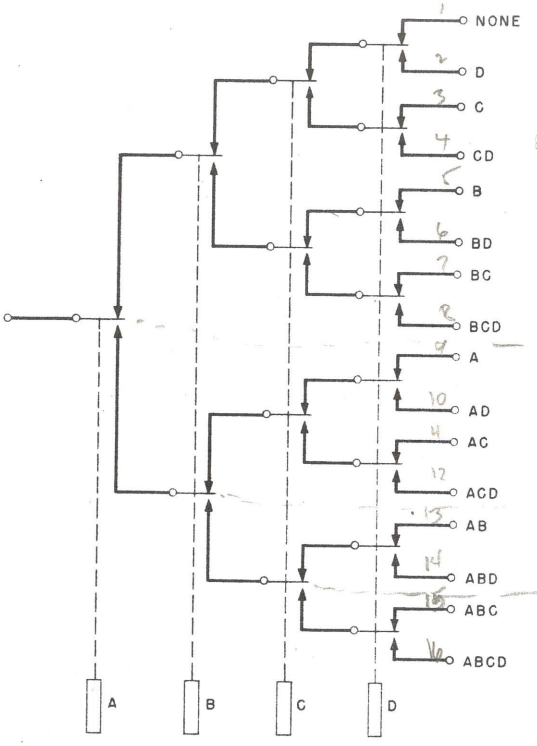


Figure 14-24 The Basic Four-Relay Tree

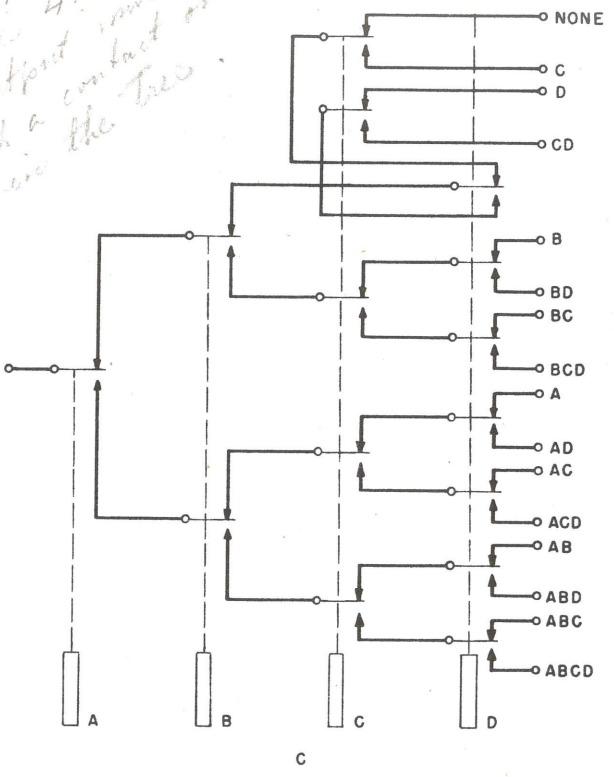


Figure 14-25 Manipulation of Tree Contacts

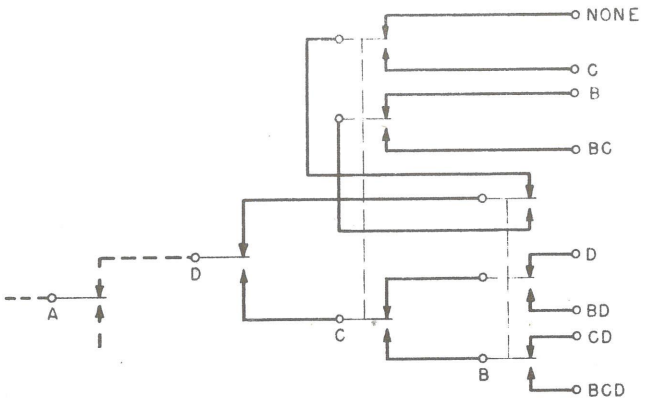


Figure 14-26 Further Tree Rearrangement

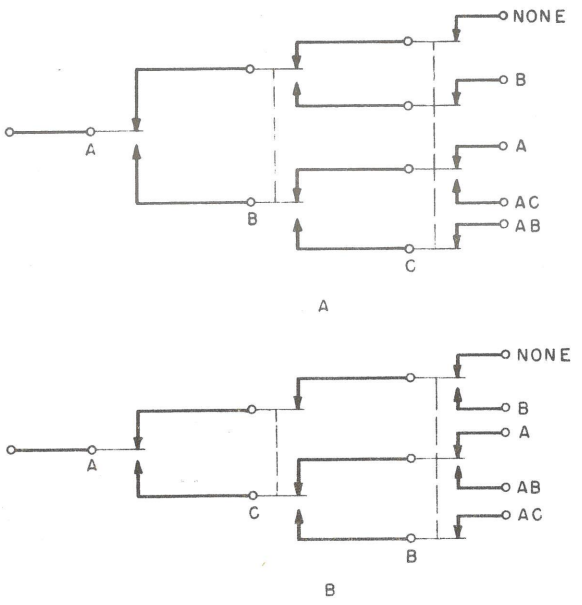


Figure 14-27 Rearrangement of an Incomplete Tree

relay (C) and the transfer on (C) placed on relay (D), as in Figure 14-25B. The output leads are redesignated, and the rearranged minor tree is reconnected to the rest of the tree. Figure 14-25C shows that relay (D) now has seven transfers and relay (C) five.

The contact manipulation of the circuit of Figure 14-25C may be continued as desired. In Figure 14-26, the upper branch on relays (B), (C), and (D) of Figure 14-25C has been rearranged by switching the transfers on (D) and (B). Note that the process of tree rearrangement is merely one of interchanging designations of the contacts comprising a minor tree; in Figure 14-26 designations B and C have been interchanged. If this rearrangement is replaced in the circuit of Figure 14-25C, the load distribution is: relay (A) one transfer, (B) four transfers, (C) five transfers, and (D) five transfers. Thus, by continued rearrangement of branches, the load may be shifted as desired, remembering that the total number of transfers will remain 2^n-1.

Similar manipulations may be performed on incomplete trees. A three-relay tree with five outputs is shown in Figure 14-27 together with a rearrangement of the tree. Here, the designations of relays (B) and (C) are interchanged and, as a result, the contact configuration was simplified. Care must be taken to insure that the tree obtained by manipulation has the same outputs as the original tree. Also it should be kept in mind that, as well as being disjunctive, each path from input to an output in a true tree must pass through a contact on each controlling relay once and only once.

14.10 TRANSFER CHAINS

Another method of disjunctively connecting a single input to a number of outputs is by means of a transfer-chain circuit. There are two general types of

these chains, as shown in Figure 14-28; one in which a path is closed to an output through the make half of the transfer, and the other which uses the break half of the transfer to close the output path. For the first type, if a number of the relays (A), (B), (C), ---, (N) are operated, only the relay nearest to the input connects through an output path. Similarly for the second type, only the released relay nearest to the input closes an output path. Obviously, transfer-chain networks are more easily controlled than the tree type of circuit, although more relays are necessary for a given number of outputs. For circuit reasons the transfers in the chains may be replaced by continuity-transfer contacts.

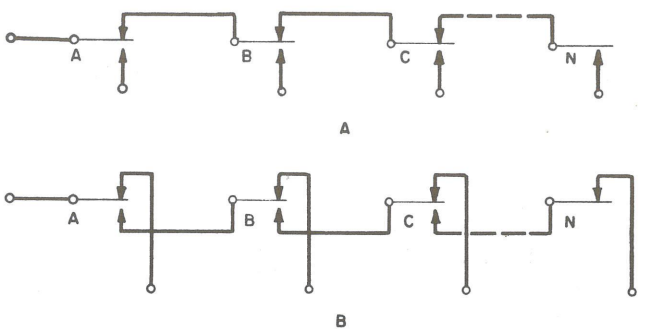


Figure 14-28 Transfer Chains

14.11 SYMMETRIC NETWORKS

A symmetric network is one in which the conditions for circuit closure can be described without designating particular relays involved in the closure. For example, a network which is closed when any three out of five relays are operated is a symmetric network. Other examples are: three out of seven relays operated, all but one of a group operated, an even (or odd) number of relays operated, and so forth. Series chains and parallel groups of make- or break-contacts are simple forms of symmetric networks, since they can indicate all relays operated or released, or at least one relay operated or released.

The design of symmetric networks is not merely an exercise in contact manipulation; such networks perform several useful functions in the telephone system. One of the most important of these is the check function. It is often necessary to give an alarm unless a certain number of relays, and no more or no less, operate at some given time. A symmetric network is a convenient one to employ for this purpose. The desirability of such a check will become more evident in later study of switching systems.

There are two symmetric networks on two relays and each of these may be connected in two ways. The circuits for "both operated or both released" are shown in Figure 14-29, and those for "only one of two operated" in Figure 14-30. It is interesting to note that in this second figure, in which a path is closed if (A) or (B) is operated (but not both), the "or" is the mutually exclusive "or"—differing from the "or" which indicates a network of parallel contacts.

Many simple symmetric networks can be developed based on chains of makes, breaks and transfers combined in various ways. Several of these are illustrated in Figure 14-31 together with the associated conditions for network closure. For some of the networks two output terminals are shown, one for each closure condition

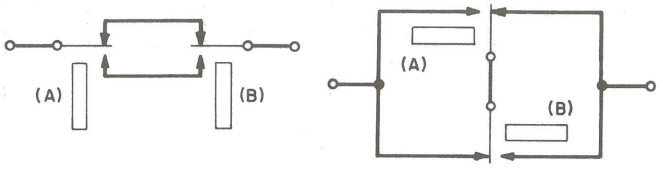


Figure 14-29 A "Both Operated or Both Released" Symmetric Circuit

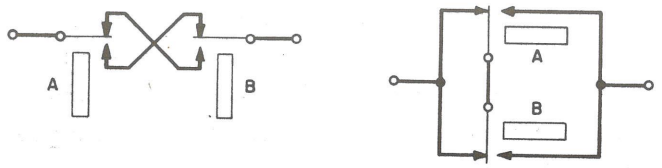


Figure 14-30 An "Only One of Two Operated" Symmetric Circuit

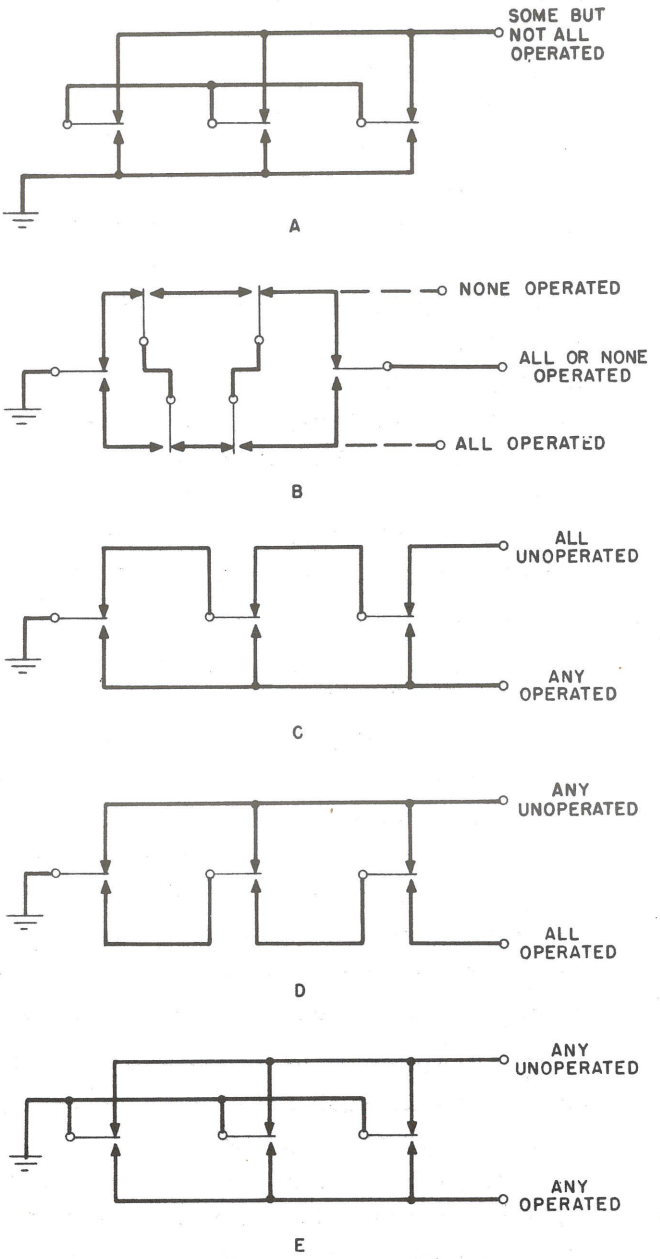


Figure 14-31 Symmetric Circuits Based on Chains of Makes, Breaks, and Transfers

for that network. The two outputs may be connected together if only a single indication is desired for both conditions.

A network for any symmetric circuit may be constructed using only series and parallel elements. However, such a network is usually complicated and uneconomical. A general type of lattice structure which gives the most satisfactory circuit is drawn in Figure 14-32. This figure shows the circuit in conventional notation and also in symbolic form in which each contact is represented by a line segment. Inspection of the circuit indicates that the network is disjunctive and that the particular output cut through to the input terminal depends only on the number of relays operated. The designating numbers of the output terminals correspond to the number of operated relays.

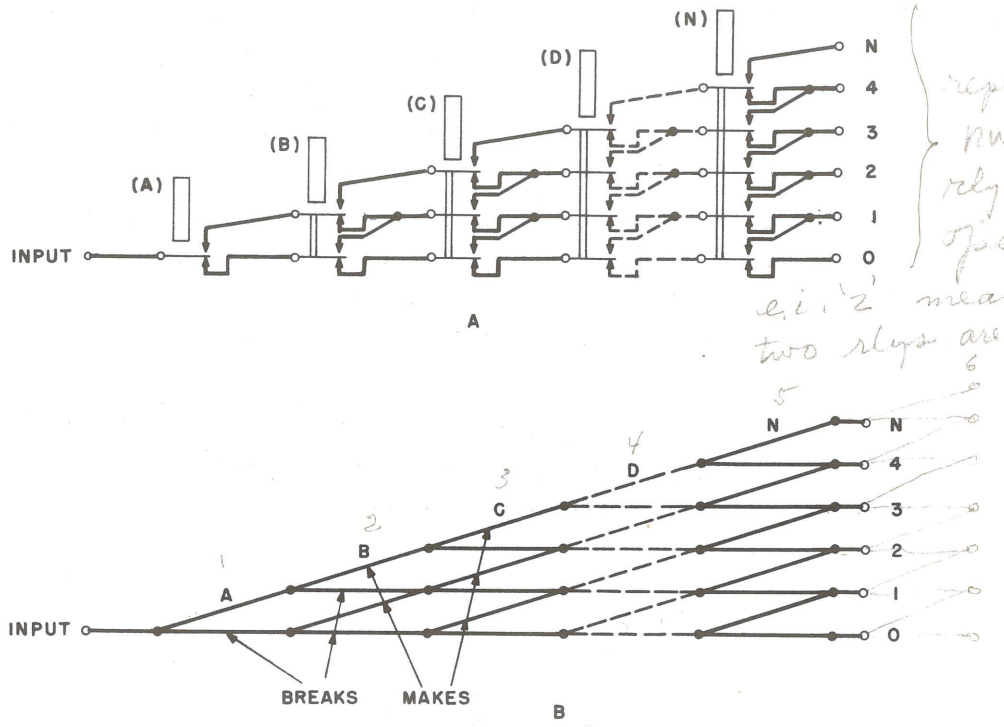


Figure 14-32 A General Symmetric Network and Its Symbolic Drawing Form

The action of the circuit is more easily seen from the second illustration of Figure 14-32. If ground is applied to the input terminal and no relays are operated, ground will be connected through a chain of back contacts on level zero of the illustration to the output terminal 0. If any one relay is operated, ground will pass along the zero level until it encounters the make on the operated relay where it will be switched up to the next or first level. The ground then remains on the first level and will appear on terminal 1. If more than one relay is operated, the ground will be passed from one level to the next higher level at each operated relay. The highest level reached will correspond to the number of relays operated.

To satisfy a given condition with this network, it is only necessary to connect to the input and to the desired output terminal and eliminate all superfluous contacts. A circuit for "two out of five" relays operated is indicated in Figure 14-33. The figure shows the circuit both as a lattice diagram and in more conventional forms. Many of the junction points on the lattice diagram can represent transfers facing in either direction; an arrangement with fewer springs will result if the circuit is drawn from both ends with transfers facing away from the ends. In the circuit form of Figure 14-33B, the (D) and (E) relays have been inverted top to bottom to obtain a simpler appearing diagram. On an actual working diagram the circuit will often appear as in Figure 14-33C. Comparison of the three forms in Figure 14-23 illustrates the advantage of the simplified circuit notation.

There is no known manner of redistributing the spring load of a symmetric circuit to give a more uniform spring load. Certain relays must necessarily carry more springs than others. However, since the circuit is symmetric, it makes no difference which particular relays in the group carry the heavy spring load, and if certain relays have a heavy load for other functions they may be favored in the symmetric circuit arrangement.

When the circuit is to be closed for two or more combinations, the output points representing these combinations may be connected together and the superfluous parts of the circuit eliminated. An arrangement for closure when either one or four out of seven relays are operated is shown in Figure 14-34 as an example.

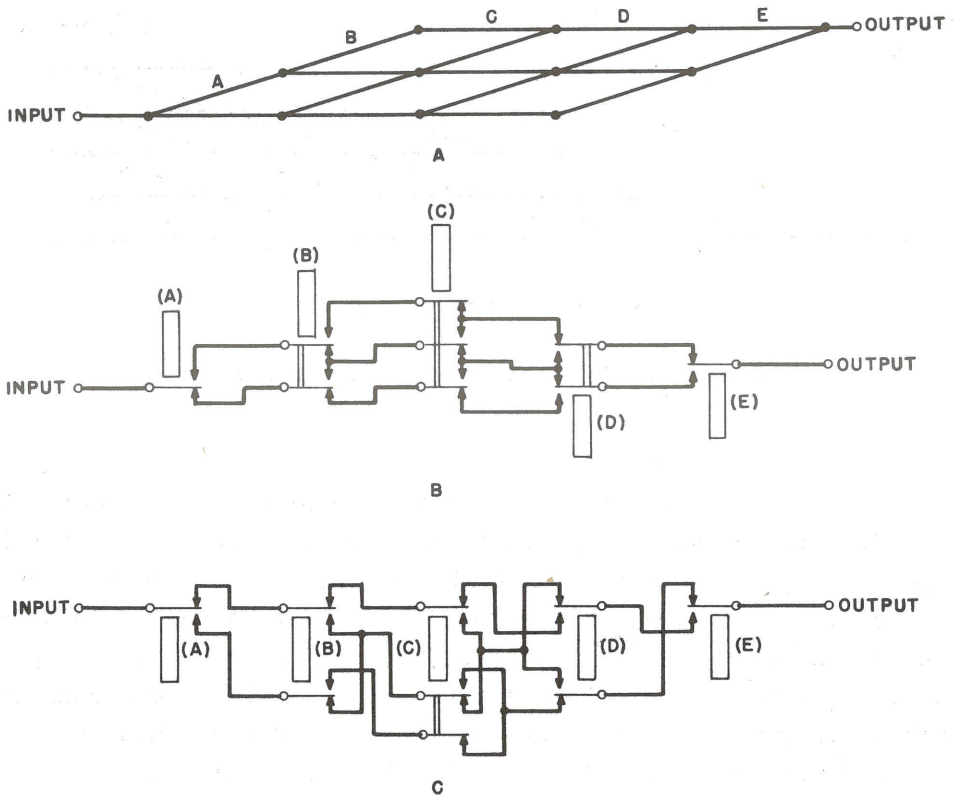


Figure 14-33 The "Two-Out-of-Five" Network

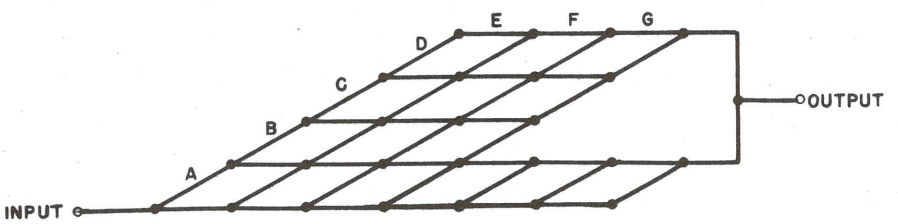


Figure 14-34 Symmetric Network for "One-or-Four-Out-of-Seven"

Where the circuit is to be closed for several combinations and the numbers of relays operated form an arithmetic series (a series in which successive numbers differ from one another by the same amount), the circuit can be simplified by "shifting down" a higher level to coincide with a lower one. For example, a circuit might be required to be closed when either none, three, or six of seven relays are operated. The third level of the symmetric diagram can then be shifted down to coincide with the zero level, as shown in Figure 14-35.

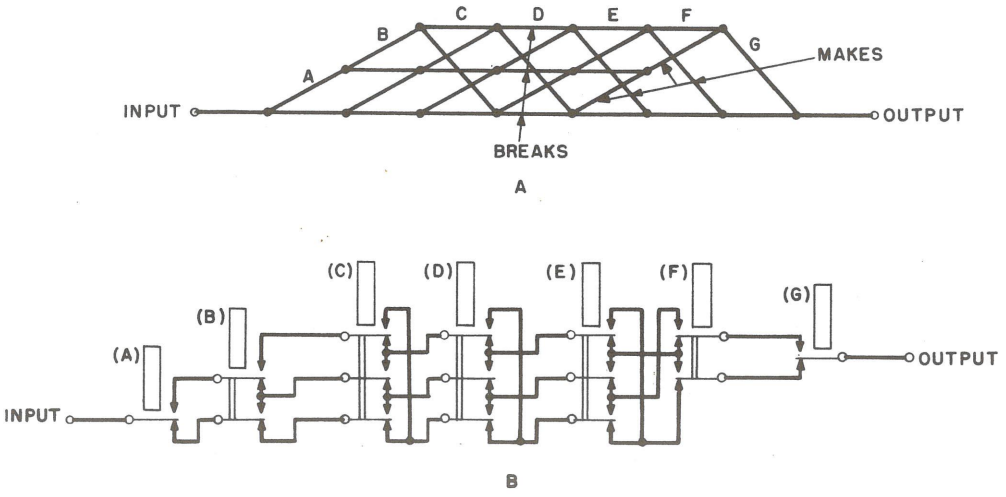


Figure 14-35 "Shifting Down" a Symmetric Circuit

CHAPTER 15

SWITCHING (BOOLEAN) ALGEBRA AND RELAY CONTACT NETWORK MANIPULATION

15.1 GENERAL

In the design of relay switching circuits, rearrangements of contact networks are often necessary either to reduce the number of contacts, or to meet requirements as to the number of springs permissible on a certain relay. Usually these network manipulations and simplifications are performed by methods of inspection similar to those indicated in Chapter 14. However, to carry out the manipulations in this manner with some facility considerable experience is necessary. The designer learns to recognize certain network configurations together with possible rearrangements and develops his own favorite rules. During the design process the circuit must be redrawn repeatedly to afford a check on the validity of the manipulations employed. The simple examples in the last chapter indicate that the simplification by inspection may become tedious and time consuming.

15.2 ALGEBRA OF LOGIC AS APPLIED TO RELAY CONTACT NETWORKS

To expedite relay contact network design and manipulation, the algebra of logic, first presented in 1847 by George Boole, can be used.[1] The title "Switching Algebra" refers to this system of algebra as it is applied in relay circuit design. The first systematic application of Boolean algebra to switching circuits was made by C. E. Shannon in a paper presented at the Institute of Electrical Engineers summer convention in 1938.[2]

The similarity between a proposition in logic and a contact network has already been mentioned in Chapter 14, together with the equivalence of dependent conditions for the proposition and the network. It is due to this equivalence that the algebra of Boole can be employed in the design and manipulation of contact networks. In many respects the application of the algebra to switching is broader than in formal logic. For example, further development of a proposition in logic which has been proven false is useless, but in relay circuits considerable use is made of "false" contacts (break contacts) or false propositions (open networks).

---

[1] G. Boole, The Mathematical Analysis of Logic (Cambridge, 1847). An Investigation of the Laws of Thought (London, 1854; reprinted Chicago, 1916).

[2] C. E. Shannon, A Symbolic Analysis of Relay and Switching Circuits (Trans. A.I.E.E., Vol. 57, 1938).

It is also interesting to note that the paradoxes in logic, when replaced by relay circuit equivalents, result in "buzzing" or "pumping" conditions*.

It should be emphasized that Boolean algebra as applied to switching is merely a convenient tool which, in the hands of the circuit designer, eases the tediousness of manipulating contact networks.

15.3 SYMBOLIC NOTATION IN SWITCHING ALGEBRA

In switching algebra upper-case (capital) letters, in general, are employed to indicate either two-terminal contact networks or single contacts of a relay, or the relay itself. Specifically, in almost all cases a letter is used for each contact; all contacts on the same relay are identified by the same letter. A primed letter indicates a contact (or a network) which is the negative of the contact, or network, designated by the same letter unprimed. For convenience, make-contacts are designated by unprimed letters. Finally, a series connection is indicated by a sign of addition, and a parallel connection by a sign of multiplication. To illustrate: A + B' is the notation for a make-contact on relay (A) in series with a break contact on relay (B); AB' indicates a parallel connection of the same contacts. A relay is represented by a single upper-case letter surrounded by parentheses.

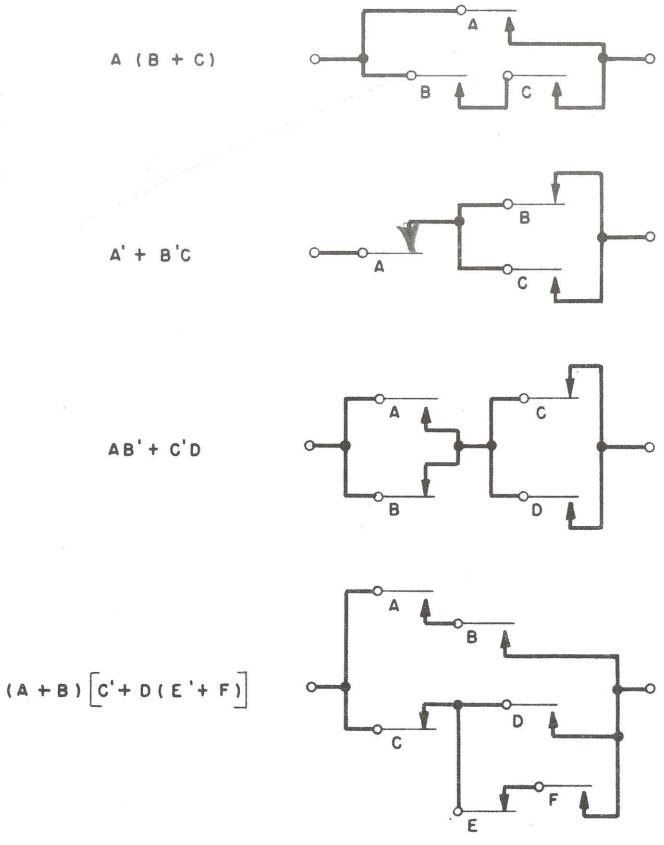


Figure 15-1 Simple Networks and Their Algebraic Equivalents

By the use of brackets more complicated networks may be represented by the algebra. For example, the expressions A(B+C), A'+B'C, AB'+C'D, and (A+B)[C'+D(E'+F)] correspond to the two-terminal networks shown in Figure 15-1. Any series-parallel two-terminal network may be represented in this fashion. The convenience of such notation is obvious.

In numerical algebra the symbols may represent variables, each of which may assume one of a number of values in a particular set of circumstances. This is true also of switching algebra with the limitation that, since

*A relay circuit which oscillates is said to "buzz" or "pump".

contacts and contact networks are two-valued devices, each variable can take on only one of two values, values corresponding either to an open or to a closed path. In the algebraic notation, the symbol 0 is arbitrarily assigned to a closed circuit, and 1 to an open circuit. That is, a closed circuit is said to have zero hindrance, and an open a hindrance of unity. Thus, the quality of hindrance is somewhat analogous to resistance.

15.4 THE POSTULATES OF THE ALGEBRA

As an essential preliminary to the formulation of a workable algebra, a set of postulates must be laid down, providing a suitable foundation. These postulates appear in the table to follow:

Table of Postulates

1.		At any given time either X = 0 or X = 1, where X represents either a single contact or a two-terminal network.	
2.	(a)	$0 \cdot 0 = 0$	A closed circuit in parallel with a closed circuit is a closed circuit.
	(b)	$1 + 1 = 1$	An open circuit in series with an open circuit is an open circuit.
3.	(a)	$1 \cdot 1 = 1$	An open circuit in parallel with an open circuit is an open circuit.
	(b)	$0 + 0 = 0$	A closed circuit in series with a closed circuit is a closed circuit.
4.	(a)	$1 \cdot 0 = 0 \cdot 1 = 0$	An open circuit in parallel with a closed circuit taken in either order is a closed circuit.
	(b)	$0 + 1 = 1 + 0 = 1$	A closed circuit in series with an open circuit taken in either order is an open circuit.

Note that the word "circuit" in the above table refers only to contact networks and not to combinations of contacts and relay windings, since the winding of a relay has a hindrance neither of zero nor of unity.

In postulate 1 it is assumed that all contacts on relay (X) act simultaneously, since X may have multiple appearances in an equation. Each appearance of X indicates a contact on (X) and, for postulate 1 to be justifiable, each X must be equal at all time to every other X. Though this restriction is often of not too great importance, it should be kept in mind since the phenomena of contact stagger can cause undesired effects.

The postulates 2 through 4 and the theorems to follow are arranged in pairs to indicate the duality that exists between the processes of multiplication and addition, and between the hindrance quantities zero and one. If, in any postulate, the zeros and ones are interchanged, the multiplications and additions interchanged,

the result will be the postulate which is the dual of the original postulate. Since the postulates exhibit that this duality is a perfect one, the dual of a theorem is proved if the theorem is proved.

15.5 THEOREMS—ADDITION AND MULTIPLICATION

Theorems in switching algebra may be considered as statements of fundamental rearrangements which may be made in a circuit without affecting its action. This section covers those theorems which influence the multiplication and addition of contact symbols as follows:

(1a) $X + Y = Y + X$

(1b) $XY = YX$

(2a) $X + Y + Z = (X + Y) + Z = X + (Y + Z)$

(2b) $XYZ = (XY)Z = X(YZ)$

(3a) $X(Y + Z) = XY + XZ$

(3b) $X + YZ = (X + Y)(X + Z)$

(4a) $X + X = X$

(4b) $XX = X$

(5a) $X + XY = X$

(5b) $X(X + Y) = X$

The first two theorems and their duals merely indicate that the grouping of symbols or the order in which they are taken has no effect upon the value of a symbolic equation, an obvious characteristic of contact networks. Theorem (3b) is not true in numerical algebra though its dual, theorem (3a), is the familiar distributive law which makes the factoring process possible. Theorems (4a) and (4b) show that identical contacts on the same relay, or identical networks, connected in either series or parallel are exactly equivalent to a single contact, or network. Theorems (3) and (5) are particularly useful in network simplification.

To prove completely each of the above theorems, and those to follow, would be space-consuming. Many of the theorems can be proved by utilizing more basic theorems in conjunction with the postulates; but although such a method might be attractive, it depends upon a different algebraic manipulation for each theorem to be proved. A method of proof which may be used in identical fashion for every theorem is that of "perfect induction", testing the theorem for all possible values of the variables. This procedure is practicable since each variable can have but two values.

As an illustration of the method of perfect induction, theorem (5b) will be verified. A table is constructed, as in Figure 15-2, which gives each possible combination in which the variables can occur. For every combination the values for each side of the theorem are entered. By means of the postulates the left side of the theorem is simplified and shown equal to either 0 or 1.

Possible Values for X and Y		Left Side of Theorem	Right Side of Theorem
X	Y	X(X + Y)	X
1	1	1(1 + 1) = 1·1 = 1	1
1	0	1(1 + 0) = 1·1 = 1	1
0	1	0(0 + 1) = 0·1 = 0	0
0	0	0(0 + 0) = 0·0 = 0	0

Figure 15-2 Proof of Switching Algebra Theorem (5b) by Perfect Induction

By this system is is proved that, for every possible combination of values of the variables, the two sides of the theorem are equal, and, hence, the theorem is a true statement under all conditions. Every theorem can be completely proved in this same manner. However, for most of the theorems contained in this chapter, examination of the corresponding circuits is usually sufficient to provide assurance of the validity of a theorem.

Although the application of the theorems already presented is fairly obvious, some discussion of theorems (3a) and (3b) should be enlightening. Theorem (3a) allows cross-multiplication as in numerical algebra. For example:

$$(A + B)(C + D) = A(C + D) + B(C + D)$$
$$= AC + AD + BC + BD$$

The corresponding circuits are shown in Figure 15-3 which also shows how the "sum of products" form can be obtained in a single step by the ordinary rules of algebra. In this example the final circuit contains more contacts than the original circuit. However, this particular manipulation has been helpful in that, while the original expression shows at a glance the conditions necessary for circuit closure, the final expression shows the conditions for opening the circuit. That is, the

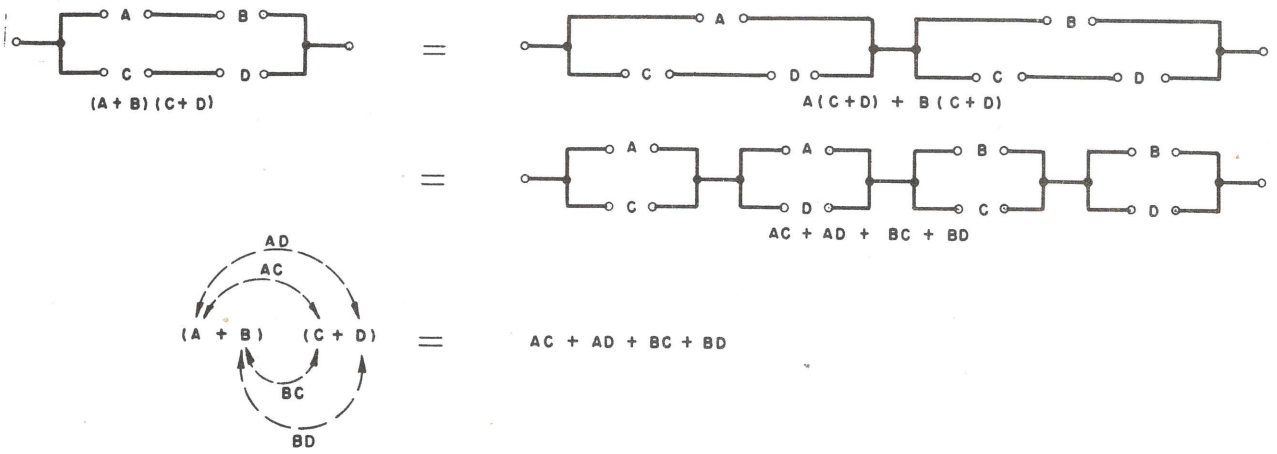


Figure 15-3 Cross-Multiplication in Switching Algebra

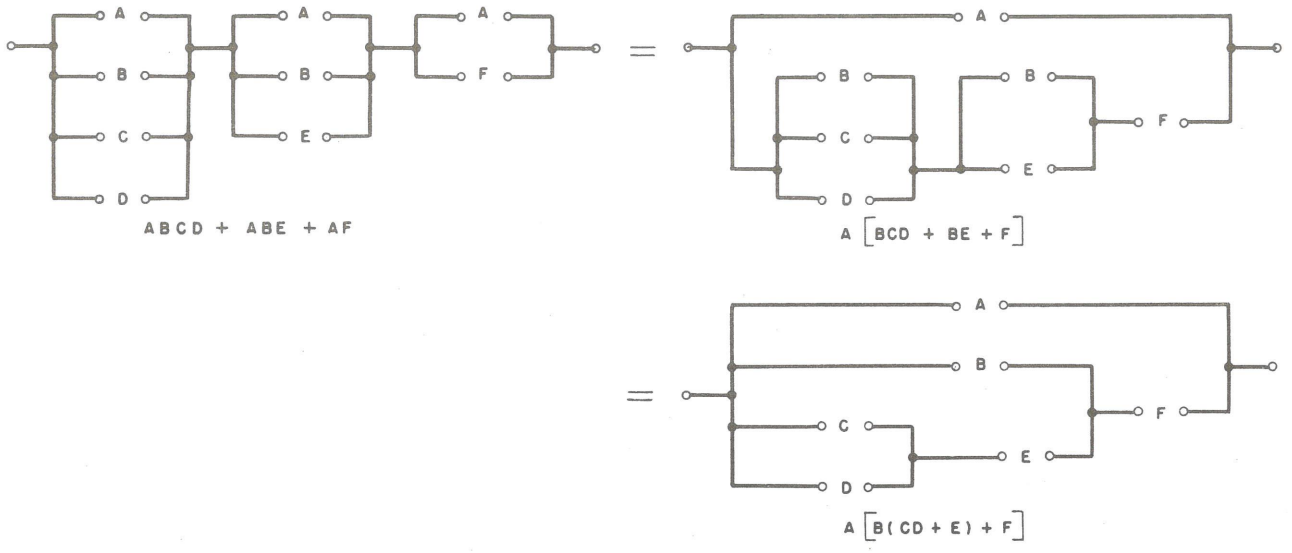


Figure 15-4 Network Simplification by Factoring

expression (A + B)(C + D) indicates a closed circuit if A and B, or C and D, are closed; the expression [AC + AD + BC + BD] shows that the circuit will be opened if one of the following are open: A and C, A and D, B and C, or B and D. By the use of this theorem any circuit composed of series groups of parallel contacts can be put in the form of parallel chains of series contacts, and vice versa.

Theorem (3a) may also be applied in factoring an expression. For example:

$$ABCD + ABE + AF = A[BCD + BE + F]$$
$$= A[B(CD + E) + F]$$

Circuit paths are shown in Figure 15-4. Note that two A contacts and one B contact have been eliminated.

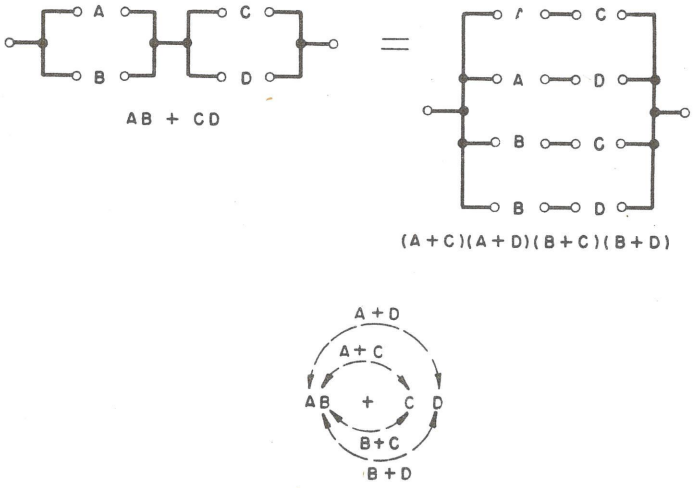


Figure 15-5 Boolean "Cross-Addition"

By means of theorem (3b) it is possible to "cross-add", which is the dual of cross-multiplication. This manipulation also indicates conditions for circuit closure and for opening the circuit. To illustrate:

$$AB + CD = (A + CD)(B + CD)$$
$$= (A + C)(A + D)(B + C)(B + D)$$

Figure 15-5, showing the corresponding circuits, clearly indicates the duality between this and the process illustrated in Figure 15-3.

The dual of the manipulation of Figure 15-4 is given by the following example, illustrated in Figure 15-6.

$$\begin{aligned}(A + B + C + D)(A + B + E)(A + F) &= (A + B + C + D)[A + (B + E)(F)] \\ &= A + (B + C + D)(B + E)(F) \\ &= A + [B + (C + D)E]F\end{aligned}$$

These two theorems, (3a) and (3b), perform operations similar to those applied in combining contacts as indicated in Chapter 14. However, the use of the theorems simplifies the process considerably.

The manner in which the theorems supplement one another is shown by the following exercise. Theorem (3b) states that the multiplication of (X + Y) and (X + Z) will result in X + YZ. This operation is carried out below. In this example and hereafter the theorems utilized will be indicated by numbers in the right margin.

$$\begin{aligned}(X + Y)(X + Z) &= XX + XZ + XY + YZ && (3a) \\ &= (X + XZ) + XY + YZ && (4b) \\ &= X + XY + YZ && (5a) \\ &= X + YZ && (5a) \\ &= (X + Y)(X + Z) && (3b)\end{aligned}$$

From a given algebraic expression it is often possible to derive other algebraic expressions representing more simple circuit forms. However, as the above exercise shows, it is also possible to work in a circle, ending with the expression originally given. Thus, it is necessary to recognize when an acceptable circuit configuration has been obtained and to stop at that point.

15.6 THEOREMS ON NEGATIVES

As discussed in Chapter 14, the negative of a contact network X is a network which is a closed path under all conditions for which X is open, and is open under those conditions for which X is closed. The basic relations between a contact network and its negative can be briefly expressed by the two theorems (6a) and (6b).

(6a) $(X)' = X'$

(6b) $(X')' = X$

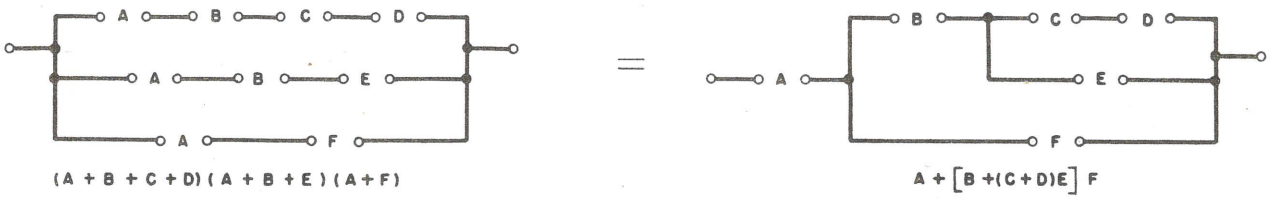


Figure 15-6 Network Simplification by Theorem (3b)

Theorem (6a) states that the negative of X is X'; and (6b), that the negative of the negative of a contact network X is X. It was also set forth in Chapter 14, without proof, that the negative of a network could be derived by taking the negative of each contact in the original network and substituting series paths for parallel paths and vice versa. Similarly, for obtaining the negative of an algebraic expression, substitute addition for multiplication and multiplication for addition, observing all brackets either present or implied, and replace for each variable its negative.

The theorems expressing this rule are:

(7a) $(X + Y + Z \ldots .)' = X' \cdot Y' \cdot Z' \ldots .$

(7b) $(X \cdot Y \cdot Z \ldots .)' = X' + Y' + Z' \ldots .$

The proof of these may be obtained for two variables by the method of perfect induction and then extended to any number of variables by mathematical induction.

As a demonstration of the application of the rule, consider the simple case shown in Figure 15-7:

$$\text{Network} = AB' + C'D$$
$$\text{Negative} = (AB')' \cdot (C'D)'$$
$$= (A' + B)(C + D')$$

A symbol which is often used to represent the statement of conditions for which network X is closed is f(X). Thus, the two equations equivalent to the circuits in Figure 15-7 are:

$$f(X) = AB' + C'D$$
$$[f(X)]' = (A' + B)(C + D')$$

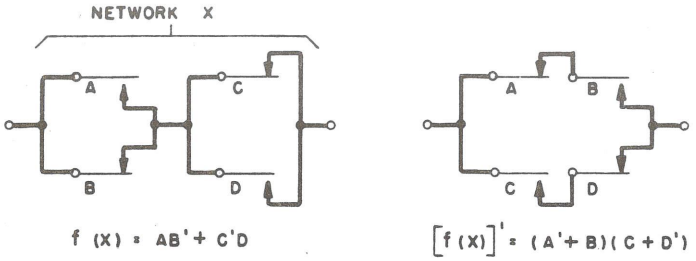


Figure 15-7 A Network and Its Negative

A more elaborate example of a network and its negative appears in Figure 15-8:

$$f(X) = A[B' + C(D' + E'F)]$$
$$[f(X)]' = A' + B[C' + D(E + F')]$$

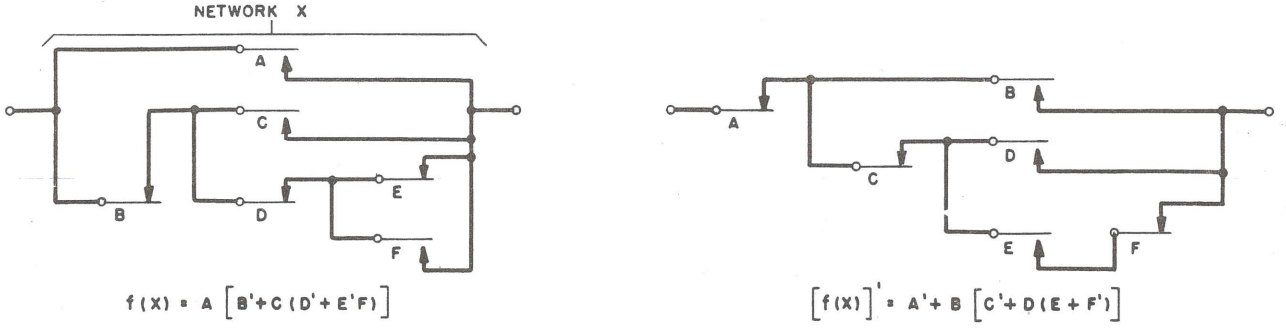


Figure 15-8 A Network and Its Negative

15.7 THEOREMS ON 0 AND 1

There are certain theorems which indicate the behavior of contact networks when combined with their negatives or with open or short circuits. These theorems are tabulated below. As before, the symbol X represents any two-terminal network of one or more contacts.

(8a) $X' + X = 1$
(8b) $X' X = 0$
(9a) $0 + X = X$
(9b) $1 \cdot X = X$
(10a) $1 + X = 1$
(10b) $0 \cdot X = 0$

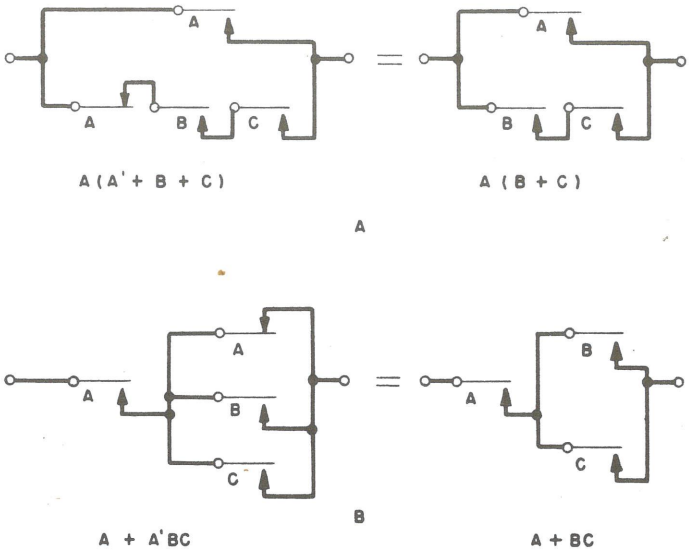


Figure 15-9 Simplification by Theorems On 0 and 1

That theorems (8a) and (8b) are valid is evident by the definition of the negative of a network. A network in series with its own negative is always equivalent to an open circuit since at any time either the network or the negative is open. Similarly, a network in parallel with its negative presents a closed path at all times since one or the other is closed at any given moment. Theorems (9a and b) and (10a and b) represent relations obvious by inspection but necessary to the algebra.

As an example of the application of these theorems, consider the circuit of Figure 15-9A:

$$\begin{aligned} A(A' + B + C) &= A'A + AB + AC && (3a) \\ &= 0 + AB + AC && (8b) \\ &= A(B + C) && (9a) \end{aligned}$$

A similar example is the dual of the above, as in Figure 15-9B:

$$\begin{aligned} A + A'BC &= (A + A')(A + BC) && (3b) \\ &= 1 \cdot (A + BC) && (8a) \\ &= (A + BC) && (9b) \end{aligned}$$

As a more complicated example, consider the circuit of Figure 15-10 which is simplified algebraically below. It would be an instructive demonstration for the reader to simplify the circuit by inspection before applying the methods of Boolean algebra.

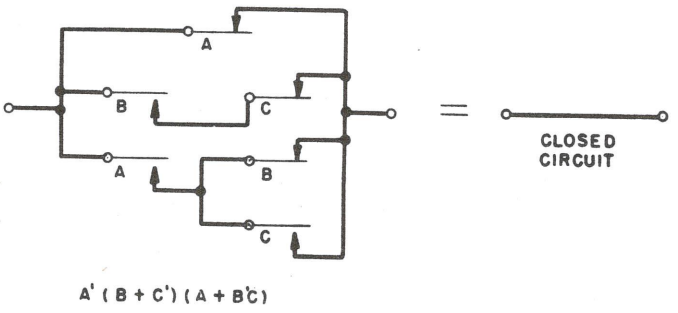


Figure 15-10 Additional Network Manipulation by Theorems on 0 and 1

$$A'(B + C')(A + B'C) = (A'B + A'C')(A + B'C) \quad (3a)$$
$$= A'AB + A'BB'C + AA'C' + A'B'C'C \quad (3a)$$
$$= 0 + 0 + 0 + 0 \quad (8b)\ (10b)$$
$$= 0;\ \text{a closed circuit.}$$

This conclusion is not obvious from a superficial study of the circuit, although a detailed analysis will show it to be true. As in most cases, the final result could have been algebraically obtained by employing different combinations of theorems or the same theorems in a different order. The selection of the theorems to be used in simplifying a circuit is not critical; the desired simplification may usually be obtained in any of several different ways.

15.8 SUPPLEMENTARY THEOREMS

Three additional theorems of some interest are as follows:

(11a) $(X + Y)(X' + Z)(Y + Z) = (X + Y)(X' + Z)$

(11b) $X Z + X'Y + YZ = XZ + X'Y$

(12) $(X + Y)(X' + Z) = XZ + X'Y$

These theorems are not as universally useful as those previously presented but perform circuit simplification which cannot be otherwise obtained. Theorem (11b) is the dual of (11a) but is not so written above; the form shown brings out the equivalence of theorems (11a) and (11b) as indicated by theorem (12). Theorem (12) is its own dual

Either (11a) or (11b) can be proved by perfect induction and the remaining two theorems derived from it. For (11a) note that in the first two brackets of the expression to the left the circuit is closed if both Y and Z are closed, regardless of the value of X. Thus, the third bracket, (Y + Z), is unnecessary.

15.9 ADDITIONAL NETWORK SIMPLIFICATION

As can be seen, the Boolean algebra makes possible more rapid and often more reliable circuit manipulation than the inspection method. A disadvantage of the algebra is that it can be directly employed only for series-parallel two-terminal networks, although it is sometimes indirectly applicable to more involved circuit arrangements. Also, there is no means, in the present state of the art, of determining when a particular algebraic manipulation has produced the most economical contact network, though this is also true of any other known method of circuit analysis.

Often, successive rearrangements of a network equation will cause unnecessary contacts to drop out. For example:

$$[A + CDE + C(D' + E')][A'(B' + D) + C]$$
$$= [A + C(DE + D' + E')][A'(B' + D) + C] \quad (3a)$$
$$= (A + C)[A'(B' + D) + C] \quad (8a)\ (9b)$$
$$= AA'(B' + D) + AC + CA'(B' + D) + C \quad (3a)$$
$$= C \quad (8b)\ (10b)\ (9a)\ (5a)$$

In the second step above $(DE + D' + E') = 1$, since, if $DE = X$, $(D' + E') = X'$.

Sometimes it becomes necessary to expand some portion of an expression in order to obtain an arrangement which permits the elimination of certain variables. Also, it may occur that the number of appearances of either one of two variables may be reduced, but not appearances of both. To illustrate this second point:

$$(A + B)(A + C)(D + C) = (A + BC)(D + C)$$
$$\text{or} = (A + B)(AD + C)$$

The form selected depends upon the spring-load requirements of the particular relays under consideration. Manipulation of a network to fulfill spring-load requirements demands some practice and complete familiarity with the theorems of the algebra.

It is always possible, for any two-terminal network, to reduce the number of contacts on any one relay to a single make and break, and these may be replaced by a transfer. Although such a configuration can be obtained by rearrangement of the Boolean expression for the network, the same result may be derived by a method now to be described.

The Boolean expression for a network X can be written in general form as:

$$f(X) = f(X_1, X_1', X_2, X_2', X_3X_3', \ldots\ldots X_k, X_k', \ldots\ldots X_n, X_n')$$

where X_k indicates appearances of make-contacts on relay (X_k), and X_k' indicates appearances of breaks on the same relay. The following equations hold:

$$f(X_1, X_1', X_2, X_2', X_3, X_3', \ldots X_n, X_n') = X_1 f(1, 0, X_2, X_2', X_3, X_3' \ldots X_n, X_n') + X_1' f(0, 1, X_2, X_2', X_3, X_3' \ldots X_n, X_n')$$
$$= X_1 [f(X)_{X_1=1, X_1'=0}] + X_1' [f(X)_{X_1=0, X_1'=1}]$$

also,

$$f(X_1, X_1', X_2, X_2', X_3, X_3', \ldots X_n, X_n')$$
$$= [X_1 + f(0, 1, X_2, X_2', X_3, X_3' \ldots X_n, X_n')][X_1' + f(1, 0, X_2, X_2', X_3, X_3' \ldots X_n, X_n')]$$
$$= [X_1 + f(X)_{X_1=0, X_1'=1}][X_1' + f(X)_{X_1=1, X_1'=0}]$$

These relations may be shown to be valid by assigning the value 1, or 0, to X_1, recalling that $X_1' = (X_1)'$ and noting that the equations become identities.

Rewriting the above expressions as theorems:

(13a) $f(X) = Af(X)_{A=1, A'=0} + A'f(X)_{A=0, A'=1}$

and

(13b) $f(X) = [A + f(X)_{A=0, A'=1}][A' + f(X)_{A=1, A'=0}]$

where A is the X_1 of the previous relation.

To interpret theorems (13a) and (13b): The contacts on relay (A) are replaced by a single make A, and a single break A', and all appearances of relay

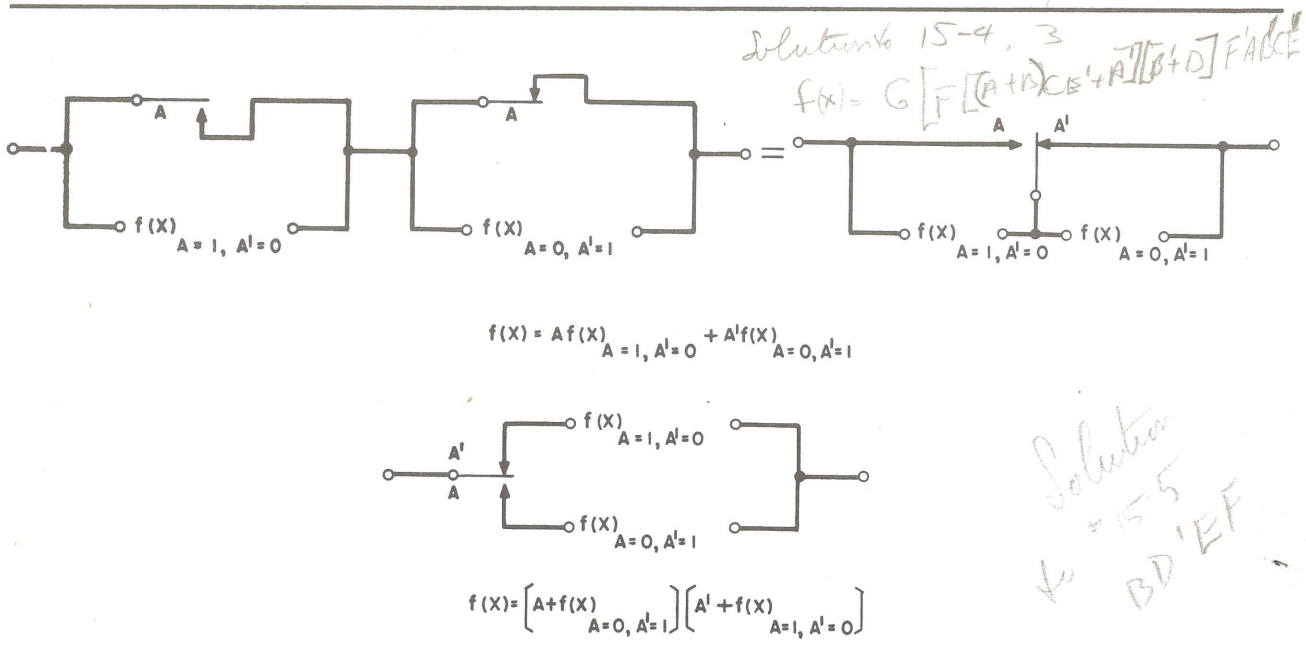
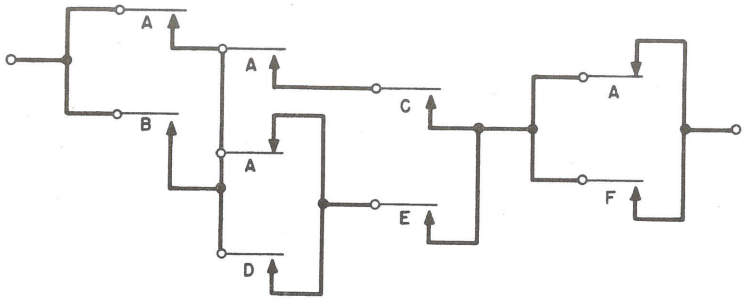


Figure 15-11 Reduction of Contacts to a Simple Transfer



f(X) = AB + (A+C)(A'D+E) + A'F

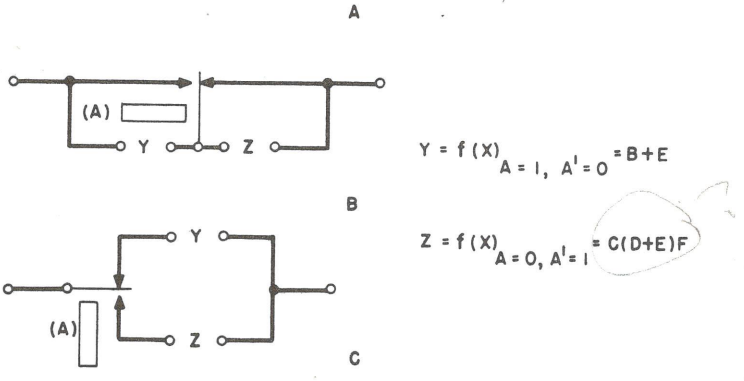


Figure 15-12 Equivalent Network Configurations

(A) contacts in the network X are replaced by open or short circuits. The network diagrams representing the theorems are shown in Figure 15-11.

As an illustration of the use of these theorems, consider the following circuit, shown in Figure 15-12A:

$$f(X) = AB+(A+C)(A'D+E)+A'F$$

It is desired to reduce the contacts on relay (A) to a single transfer, employing theorem (13a). The expression $f(X)_{A=1,A'=0}$ is determined by replacing each A in f(X) by 1, and A' by 0; likewise $f(X)_{A=0,A'=1}$ is found by substituting A by 0 and A' by 1 in the original f(X).

15-4

Solution to 3

$$f(X)_{A=1,\ A'=0} = 1\cdot B + (1 + C)(0\cdot D + E) + 0\cdot F$$
$$= B + E \qquad (9b)\ (10a)\ (10b)$$
$$f(X)_{A=0,\ A'=1} = 0\cdot B + (0 + C)(1\cdot D + E) + 1\cdot F$$
$$= C(D + E) + F$$

Inserting these values in theorem (13a), $f(X) = A(B + E) + A'[\,C(D + E) + F\,]$ and the desired arrangement is obtained. This process is known as expansion around a variable.

If theorem (13b) is utilized, an equivalent network is found: $f(X) = [A + C(D + E) + F][A' + B + E]$. Actually, the second network could be immediately derived from the first by the use of theorem (12).

The relative advantages of the two network forms is clear from a consideration of the networks themselves, as illustrated in Figures 15-12B and C. For the network of Figure 15-12C the circuit will be momentarily open as (A) acts if an ordinary break-before-make transfer is used. However, continuity is preserved in the network of Figure 15-12B even though no continuity transfer is employed. This is evident since if the action of (A) is to have no effect on the circuit, both paths Y and Z must be closed. In Figure 15-12B a path independent of A is provided through Y and Z so that a momentary open of both A and A' does not influence the network adversely.

The rearrangement indicated by theorem (12), then, is of interest since it is frequently undesirable to use continuity spring combinations to insure circuit continuity. However, the process may be applied, in general, only to two-terminal networks.

15.10 DELTA-Y TRANSFORMATIONS

A transformation similar to the Y-Delta, or star-mesh, transformations in electrical network theory exists for contact networks. The Y-Delta transformation is shown in Figure 15-13. The equivalence of the two forms may be indicated by considering all paths for all combinations of terminals taken two at a time. For example, the path between a and b in the Y form is (X + Y) while the Delta arrangement in this path is

$$(X+Y)(X+Z+Y+Z)$$
$$= X+Y \qquad (4a)\ (5b)$$

Similarly, all other terminal-to-terminal paths may be shown to be equivalent.

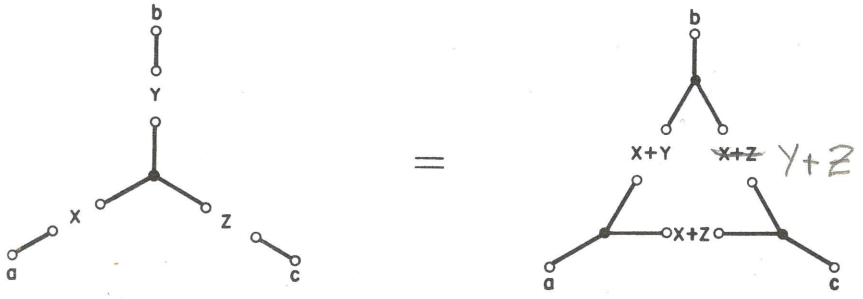


Figure 15-13 Y-Delta Transformation

The transformation from Delta to Y, in Figure 15-14, is the dual of that from Y to Delta. Here again paths between terminals in the one form are equal to those in the other. Considering paths between a and b: in the Delta arrangement the paths are expressed by $X(Z + Y)$, and in Y, $XZ + XY = X(Z + Y)$ (3a)

The Y-Delta transformation may be extended to junction points with more than three legs. This is illustrated by Figure 15-15 in which the junction has four legs, a four-element "star." The equivalent mesh arrangement consists of an element from each terminal (a, b, c, and d) connecting to every other terminal; and each of these elements is composed of the sum of the two elements connecting to the corresponding terminals of the star. The transformation holds for a star of any number of elements, although the proof is not given herein. The rules for the dual transformation, from mesh to star, are not known for all cases.

15.11 RESOLUTION OF BRIDGE-TYPE NETWORKS

Although it is impossible to treat bridge circuits directly by Boolean algebra since they cannot be described in their simplest form by the usual "and-or" relations, some rearrangements of such networks can be carried out by aid of the algebra. A bridge-type network may be expressed as a series-parallel configuration by any of three methods. The first of these results in a product of sums and is determined by tracing out all possible paths from input to output terminal. Such a process is shown as an example in Figure 15-16 for which the algebraic expression is:

$$f(X) = (A+C)(A+E+D)(B+E+C)(B+D)$$

where X represents the network as a whole.

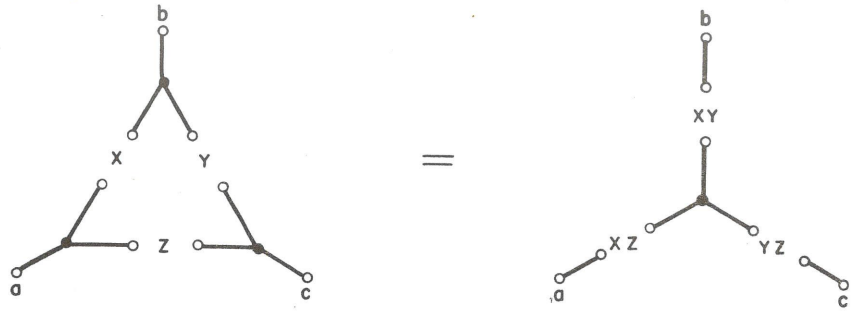


Figure 15-14 Delta-Y Transformation

An alternative method is to determine all possible means by which the circuit may be opened by taking cuts across it, as in Figure 15-17. The resulting equation is:

$$f(X) = AB + BEC + AED + CD$$

In a complex network, consideration of all paths through the network becomes involved.

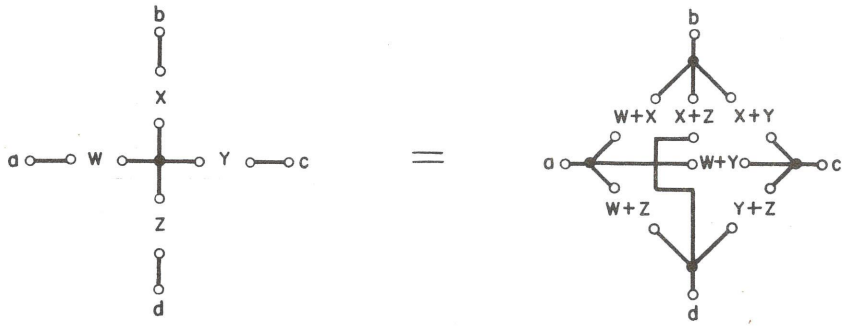


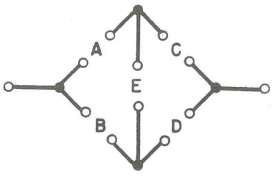
Figure 15-15 Star-Mesh Transformation

Another procedure for bridge reduction entails the use of star-mesh transformations and has the advantage over path tracing of insuring that no paths have been overlooked. Consider

the simple bridge of Figure 15-16. The junction point of A, E, and C is first transformed from Y to Delta as shown in Figure 15-18. The circuit is thus representable by the expression:

$$f(X) = (A + C)[B(A + E) + D(E + C)]$$
$$= (A + C)[B(A + E) + D][B(A + E) + (E + C)] \quad (3b)$$
$$= (A + C)(B + D)(A + E + D)(B + E + C) \quad (5a)\ (3b)$$

and equation identical to the first derived above.



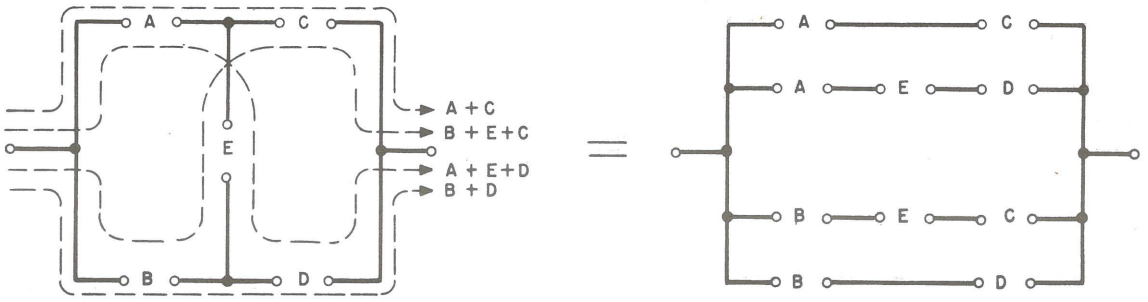


Figure 15-16 The Basic Bridge and Its Series-Parallel Network

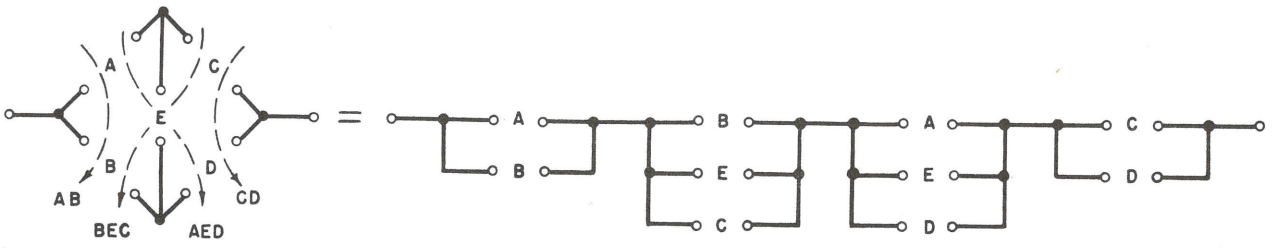


Figure 15-17 A Second Equivalent to the Basic Bridge

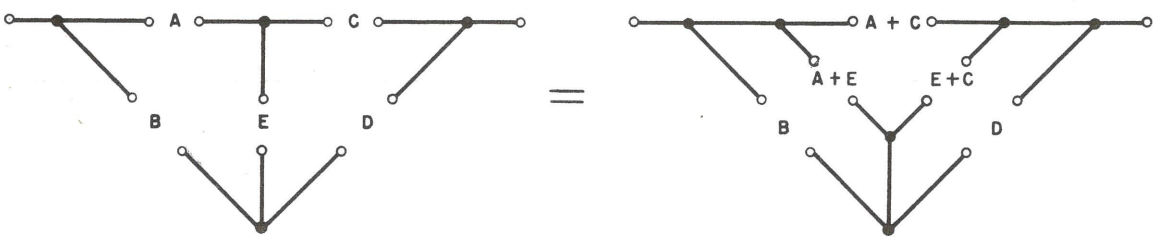


Figure 15-18 Y-Delta Transformation Applied to Bridge Manipulation

It is also possible to convert the Delta formed by segments A, E, and B of Figure 15-16 to a Y equivalent to give the network of Figure 15-19, expressed by:

$$f(X) = AB + (AE + C)(BE + D)$$
$$= AB + ABE + ADE + BCE + CD \qquad (3a)\ (4b)$$
$$= AB + BCE + AED + CD \qquad (5a)$$

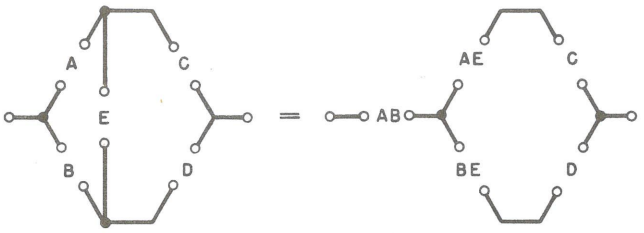


Figure 15-19 Delta-Y Transformation of Bridge

If the bridge is more complicated, several successive transformations may be necessary in the reduction of the network.

Occasionally it is convenient to synthesize a bridge network from the equivalent series-parallel arrangement. To effect such a synthesis the designer must recognize by inspection that such an equivalence exists, either from the configuration or from the algebraic expression of the network. For example, both the forms

$(A+C)[B(A+E)+D(E+C)]$ and $AB+(AE+C)(BE+D)$

indicate equivalence to bridge networks, as has been shown.

The negative of a bridge-type network can be derived from its series-parallel form by normal algebraic means. However, a more direct method may be used, provided that the network is "planar"; that is, one which may be drawn in a single plane without crossovers. To describe this process, the terms "node" and "mesh" will be used. A node is a junction point where three or more elements meet, whereas a mesh is a series of elements forming a complete closed loop. For example, in Figure 15-16 the common junction point of A, C, and E, is a node, as is also the junction of the input lead and elements A and B. Elements A, E, and B form a closed loop or mesh. The input and output leads are considered to extend indefinitely so that the space above the diagram is bounded by a mesh and that below by a second mesh. Thus, the network contains four nodes and four meshes.

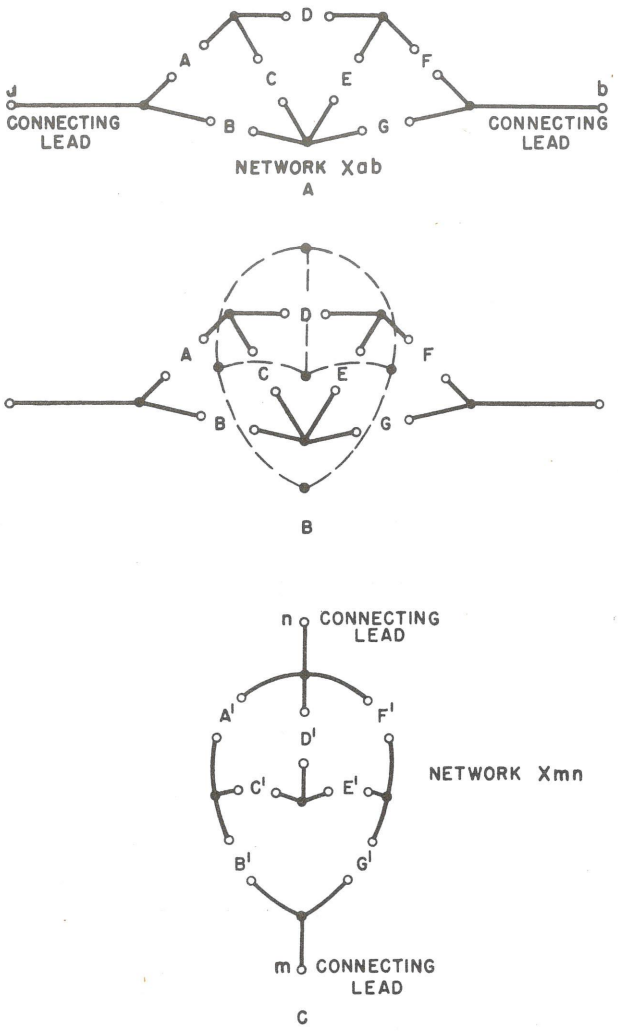


Figure 15-20 Graphical Method of Deriving Negative Network (Xab)'=Xmn

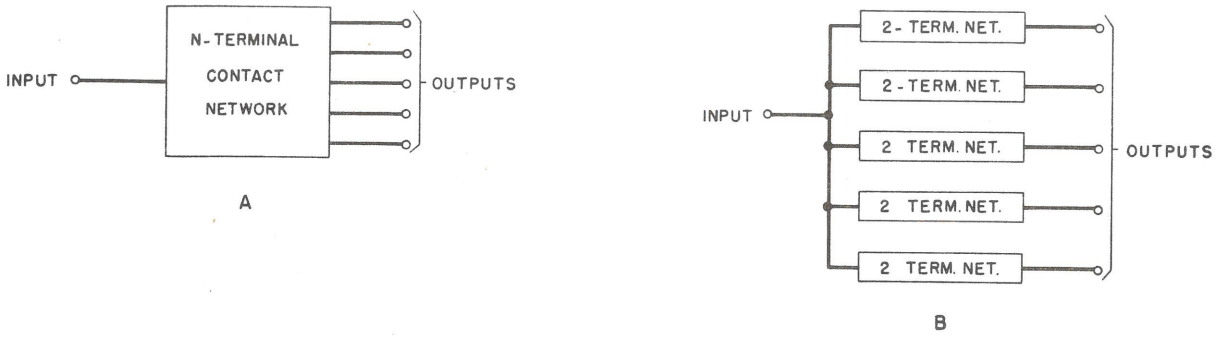
To illustrate this method of deriving the negative of a bridge-type network, consider the network of Figure 15-20A, represented by Xab, which contains five meshes. A dot is placed in the center of each mesh, as in Figure 15-20B, and the dots are connected by segments (shown by dotted lines in Figure 15-20B) in such a manner that each segment crosses one and only one element of the original network. These dots form the nodes of a new network Xmn, and the connecting segments are the elements of this network. Each segment is made the negative of the element of the original network it crosses, as in Figure 15-20C, and the new network Xmn, is the negative of the original network Xab.

To justify this method, assume that Xab = 0, a closed circuit. Then, some path through Xab must be closed, and every element of this path is closed. However, this path completely cuts the network Xmn through elements of Xmn each of which equals 1 (open circuit). Therefore, Xmn must be an open circuit. Similarly, it may be shown that if Xab = 1, Xmn = 0. Thus, (Xab)' = Xmn; the network Xmn is the negative of Xab.

The above procedure, of course, may also be applied to series-parallel networks. As is evident from the method, the negative of a planar network can always be realized with the same number of contacts as the original network. This is not generally true of non-planar networks to which no convenient method (excepting the algebra) may be applied to derive its negative.

15.12 N-TERMINAL NETWORKS

A common form of n-terminal network which may be designed and simplified with the aid of the Boolean algebra is shown in Figure 15-21A, where a single input



A BASIC TYPE OF N-TERMINAL NETWORK AND ITS REDUCTION TO N-1 TWO-TERMINAL NETWORKS

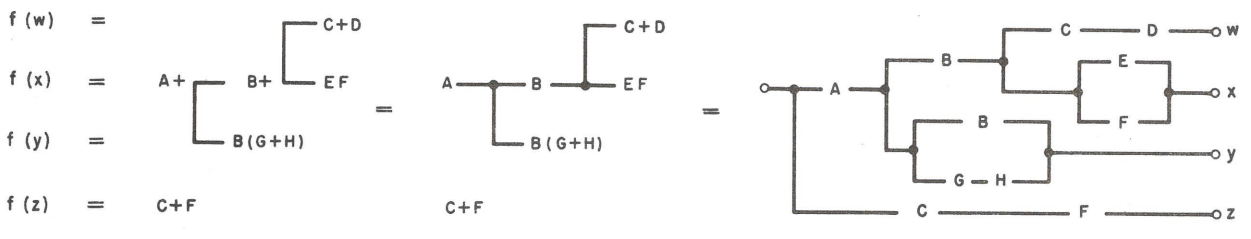


Figure 15-21 N-Terminal Networks

is connected to one or more of several outputs by a contact network. One procedure for the design of such a network consists of determining the conditions for connecting the input to each output and deriving a two-terminal network providing each of these paths, as in Figure 15-21B. Often these two-terminal networks may then be combined into a single n-terminal network, utilizing theorems such as (3b), reducing the total number of contacts required.

Consider the following four two-terminal paths for controlling four separate relays at the output of these paths. The individual paths are identified by such a symbol as f(x), read as "the path for controlling relay (X)."

$$f(w) = A + B + C + D$$
$$f(x) = A + B + EF$$
$$f(y) = A + B\,(G + H)$$
$$f(z) = C + F$$

This may be regarded as a set of "simultaneous equations" and the common elements combined as in Figure 15-21C.

The method may be most easily applied when the individual two-terminal networks are expressed as a sum of products. Similar elements, such as A and B above, are collected to the left of the simultaneous equations, the element appearing most often being first in order. In order to combine elements in a vertical line, these elements must be identical and adjacent to a common junction point. It is evident that this method of reduction allows the possibility of connecting two outputs together; isolation is not complete.

Rearrangement of a network may be necessary to permit combination with another network. For example:

$$f(x) = (A + B'C)\,(A' + B)$$
$$f(y) = AB + D$$

By applying theorem (12), f(x) may be rearranged and the paths combined:

$$f(x) = (A + B'C)\,(A' + B) = AB + A'B'C$$
$$f(y) = AB + D$$

The final simplification appears in Figure 15-22.

15.13 DISJUNCTIVE FACTORS

A factor is a symbolic expression representing one of a number of parallel networks. Two factors are said to be "disjunctive" if they are never closed at the same time. To illustrate, the factors (A + B) and (A + C) are not disjunctive, since closure of all three variables closes both paths at a time. However, the factors (A + B) and (A' + C) can never be closed together,

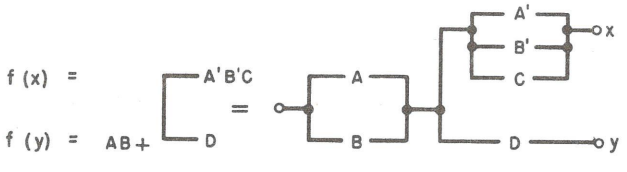


Figure 15-22 Combination of Network Paths

and are hence, disjunctive. By definition, the sum of disjunctive factors must be 1, a reliable test for disjunctivity.

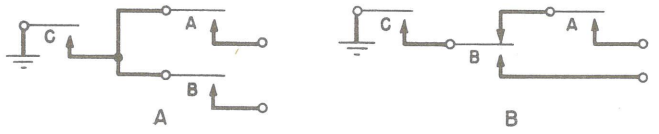


Figure 15-23 Isolation of Outputs by Use of Transfer Contact

Several factors may be mutually disjunctive. For example:

$$(A + B)(A' + C)(C' + B')$$

indicates three factors which any two taken together are disjunctive

In paragraph 15.12 several two-terminal networks were combined into a single n-terminal arrangement without, however, insuring that the outputs be completely isolated. If such isolation is desired, it is always possible to make the outputs disjunctive with respect to one another.

Consider the three-terminal network of Figure 15-23A. Here it is desired to make branches A and B disjunctive factors. This may be accomplished by the following expansion:

$$\begin{aligned} AB &= AB + B'B && (8b)\ (9a) \\ &= (AB + B')\ (AB + B) && (3b) \\ &= (A + B')\ (B + B')\ (AB + B) && (3b) \\ &= (A + B')\ B && (8a)\ (5a) \end{aligned}$$

Figure 15-23b indicates the resulting circuit in which the paths from input to each output are completely disjunctive. Since this particular manipulation can be especially useful, it is here stated as a theorem:

(14a) $XY = (X + Y')Y$

The dual of this expression is

(14b) $X + Y = XY' + Y$

The latter theorem is not used to construct disjunctive factors but is convenient in some network simplification. It is similar to theorem (12) if in this theorem Z equals unity.

In theorem (14a) element X is said to be a "disjunctive element." It cannot be shorted by action of element Y and may be combined with any other disjunctive element. Thus, in an n-terminal network connected to ground, all similar contacts on a particular relay may be combined into a single make or break, provided that each of these contact elements has just been made disjunctive with respect to its shunting paths. By making both make and break contacts of a specific relay disjunctive, the load on that relay may be reduced to a single transfer, if the network of which the contacts are a part is of the single-input type.

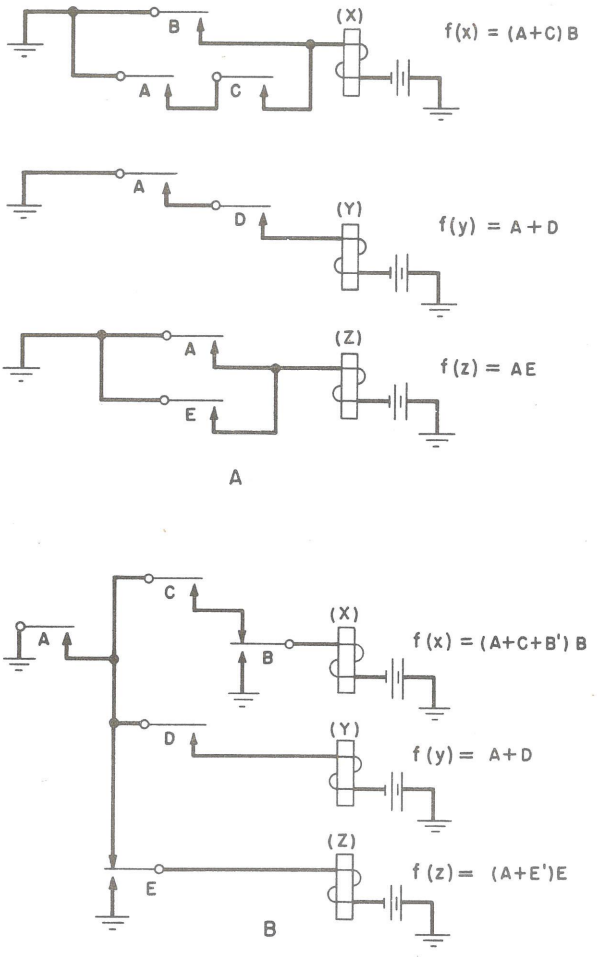


Figure 15-24 Derivation of N-Terminal Network

An elementary example of this procedure is as follows: The paths for operating relays (X), (Y), and (Z) in Figure 15-24A are:

$$f(x) = (A + C)\,B$$
$$f(y) = A + D$$
$$f(z) = AE$$

The elements A of f(x) and f(z) are made disjunctive:

$$f(x) = (A+C)\,B = (A+C+B')\,B$$
$$f(y) = A + D$$
$$f(z) = AE = (A + E')\,E$$

and are combined to obtain the network of Figure 15-24B.

Theorem (14a) is also applicable to the simplification of two-terminal networks. Consider the network of Figure 15-25A symbolized by:

$$(A + B' + C)\,(A'B + D)$$

Since the factors (A + B') and (A'B) are disjunctive, it should be possible to combine them in some manner. Applying theorem (14a),

$$A'B = A'\,(A + B)$$

then,

$$(A + B' + C)\,(A'B + D) = [(A + B') + C][A'\,(A + B) + D]$$

The network equivalent to the last expression is shown in Figure 15-25b.

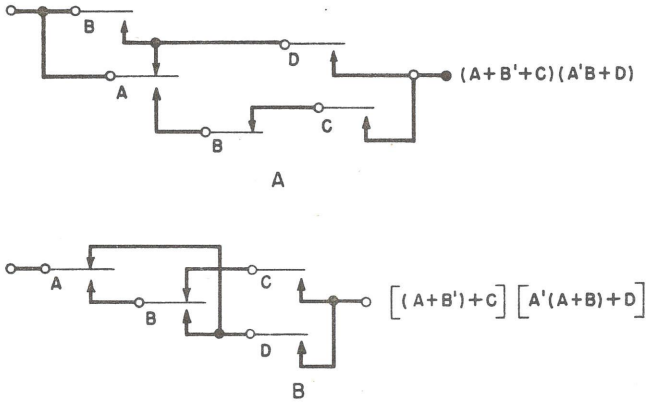


Figure 15-25 Application of Theorem (14a)

15.14 ALGEBRAIC CONSIDERATION OF BASIC RELAY OPERATING PATH

In the design of a relay circuit it occurs at times that only a few specific contacts are available to operate a particular relay. Chapter 13 discusses the basic operating and holding paths composed of various combinations of make and break contacts for relay control. However, these paths may be more conveniently derived and

manipulated by switching algebra to meet requirements imposed during the synthesis of a circuit.

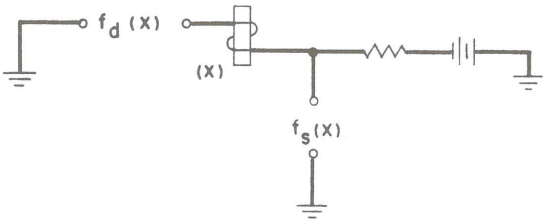


Figure 15-26 General Operation of A Relay

The basic relay circuit consists of a relay (X) with a direct operating path, $f_d(x)$, and a shunt path, $f_s(x)$, as shown in Figure 15-26. If $f(x)$ represents all conditions necessary to operate relay (X), the following equation holds:

$$f(x) = f_d(x) + [f_s(x)]'$$

where $f_s(x)$ ' is the negative of $f_s(x)$. This may be shown to be valid by perfect induction. Letting $f_d(x)$ equal zero, or short-circuit, there results:

$$f(x) = [f_s(x)]'$$

From these two expressions certain interesting relations between relay operating paths follow. By the second expression, the circuit equivalent in Figure 15-27A holds; and by the first and second, those in Figure 15-27B obtain.

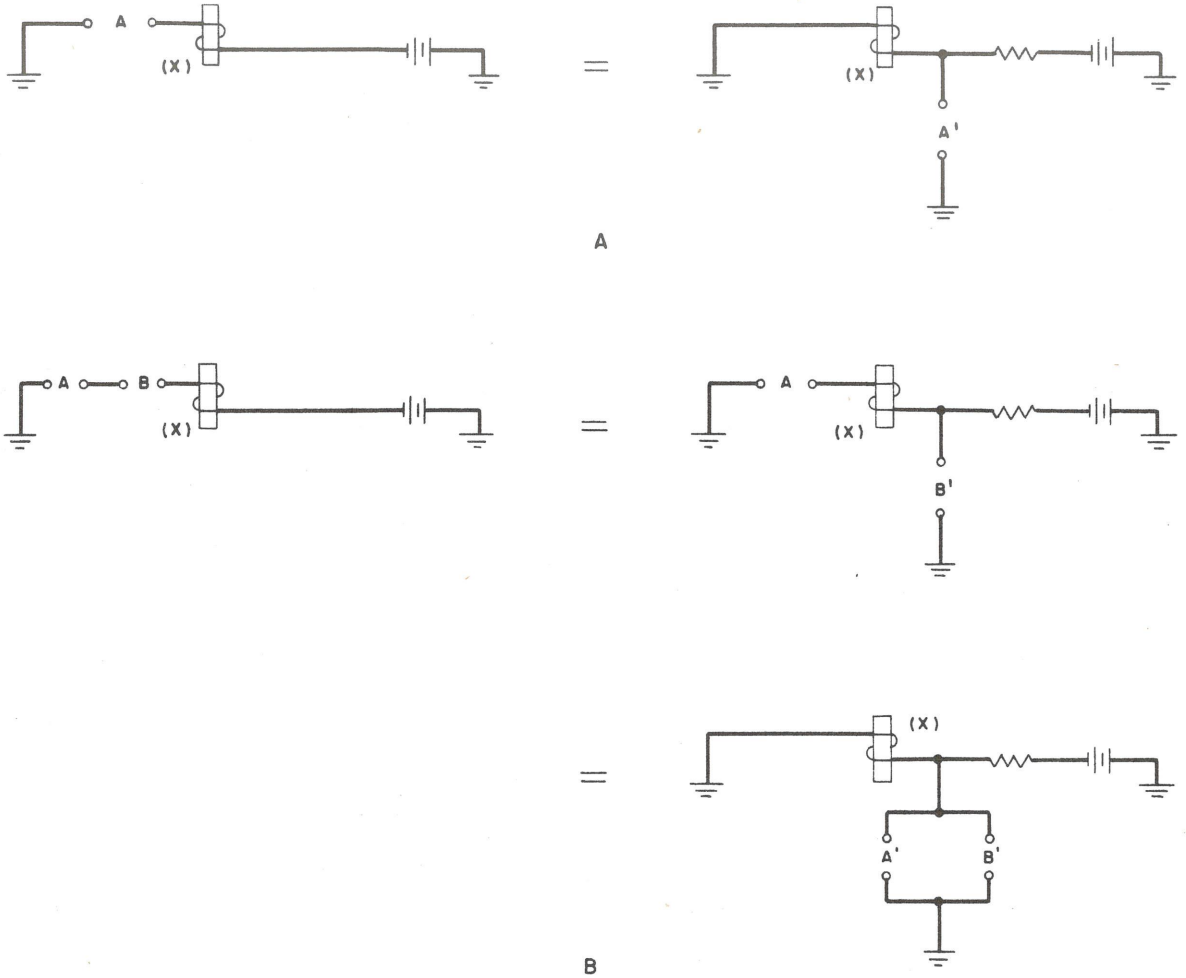
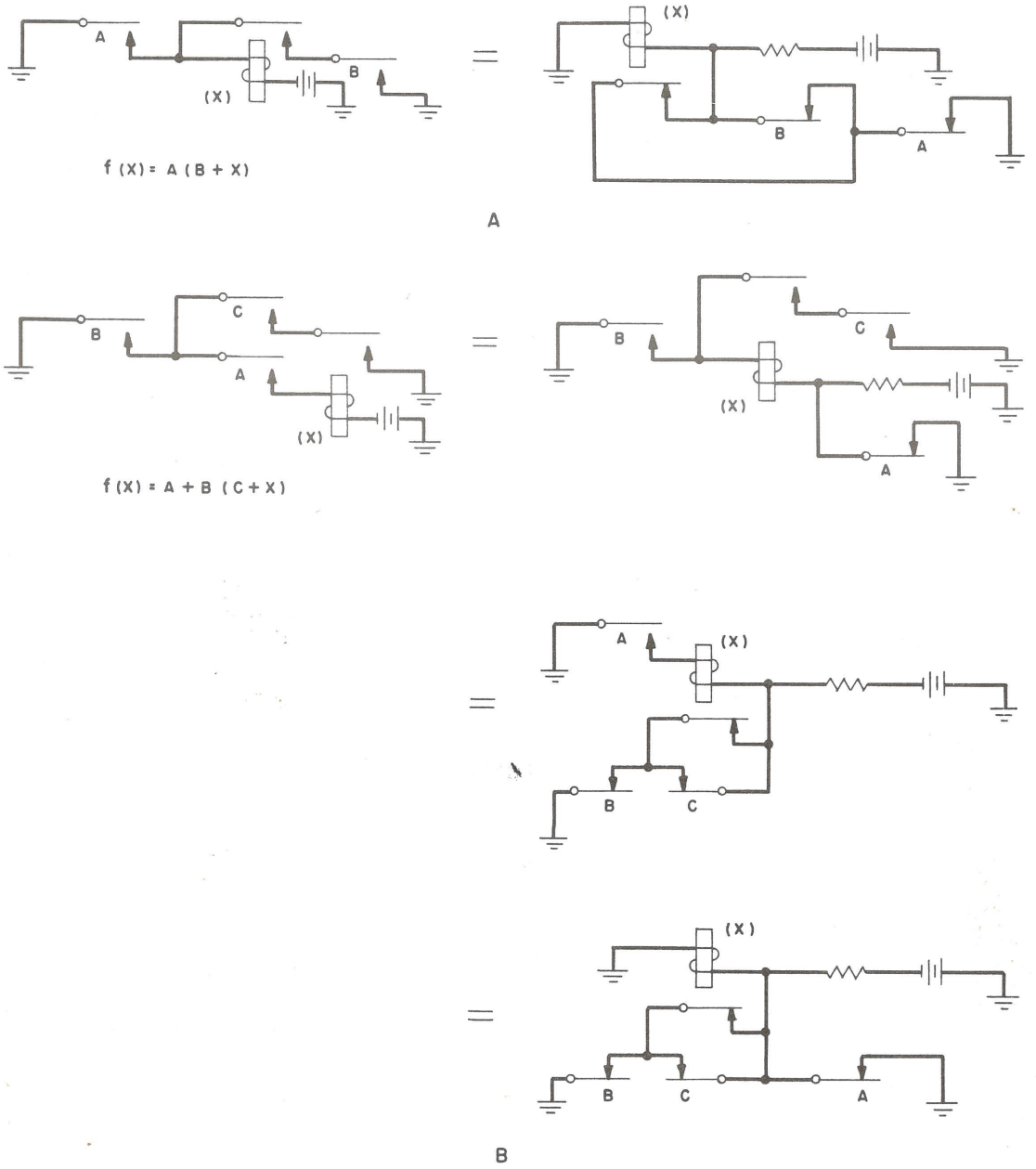


Figure 15-27 Relations Holding Between Relay Control Paths

Illustrations of the application of these relations are shown in Figure 15-28A and B.

15.15 TABLES OF COMBINATIONS

In a particular circuit of, for example, two relays (A) and (B) it is possible to have, at any given moment, one of four conditions prevailing. That is: (A) and (B) both released, (A) operated and (B) released, (A) released and (B) operated, (A) and (B) both operated. If an additional relay (C) is added, the same four conditions or combinations may obtain with (C) operated and also with (C)



B

Figure 15-28 Manipulations of Relay Control Paths

released, a total of eight combinations. Each added relay will, then, double the number of possible combinations. Thus, for n relays the total number of combinations equals 2^n.

Obviously a separate network path can be closed for each combination of controlling relays operated and released. For three relays (A), (B), and (C), the eight possible different paths are as shown in the table of Figure 15-29.

1.	A' + B' + C'	All relays released.
2.	A' + B + C'	(B) operated, (A) and (C) released.
3.	A' + B' + C	(C) operated, (A) and (B) released.
4.	A' + B + C	(B) and (C) operated, (A) released.
5.	A + B' + C'	(A) operated, (B) and (C) released.
6.	A + B + C'	(A) and (B) operated, (C) released.
7.	A + B' + C	(A) and (C) operated, (B) released.
8.	A + B + C	All relays operated.

Figure 15-29 Output Combinations for Three Relays

Note that of these eight paths one, and only one, is closed at any given time, and that some one path is always closed. Any two-terminal network on three relays can be designed from the above table by connecting the desired combinations in parallel, omitting all undesired combinations.

For convenience, a similar table, employing a different notation, is used. Here, the symbol 1 represents the released condition of a relay and 0 represents the operated condition. Such a table, the equivalent of the table of Figure 15-29 is written as in Figure 15-30.

	A	B	C
1.	1	1	1
2.	1	0	1
3.	1	1	0
4.	1	0	0
5.	0	1	1
6.	0	0	1
7.	0	1	0
8.	0	0	0

Figure 15-30 Output Combinations for Three Relays

Here again each row represents a particular operated combination of the three relays. In row 5, for instance, the notation, 0 1 1, symbolizes the combination (A) operated, (B) released, and (C) released. From the standpoint of contact network paths the symbol 1 represents a break, and 0 a make contact. It is important to avoid confusion between this notation and the 0 and 1 used in the Boolean algebra.

To derive a two-terminal network, relay combinations for closure are selected from the table of combinations. Paths representing these combinations are placed in parallel and simplified. For example, a path is to be closed for two combinations from the table of Figure 15-30:

	A	B	C
1.	1	1	1
2.	1	0	1

The algebraic notation is written and simplified:

$$(A' + B' + C')\ (A' + B + C') = A' + C' \qquad (3b)\ (8b)$$

For the first four combinations in Figure 15-30, the combinations and circuit notation are as follows:

	A	B	C
1.	1	1	1
2.	1	0	1
3.	1	1	0
4.	1	0	0

$$(A' + B' + C')\ (A' + B + C')\ (A' + B' + C)\ (A' + B + C)$$
$$= A' + (B' + C')\ (B + C')\ (B' + C)\ (B + C) \qquad (3b)$$
$$= A' \qquad (3b)\ (8b)$$

Close examination of these two examples shows that the final network forms could have been predicted from inspection of the combinations used. In the first example a closed path is desired if (A) and (C) are released, no matter what the condition of (B) is. In the second example, circuit closure is to occur for (A) released regardless of which of the four possible combinations of (B) and (C) obtains. A rule, then, which immediately suggests itself is that if, in a table of combinations describing a particular two-terminal network, <u>all</u> possible combinations of certain relays appear in series with a <u>single</u> combination of other relays, the network contacts on the former relays may be neglected. An alternate statement of the rule is as follows: when 2^n different combinations of any number of variables, m, are identical in all but n columns, contacts on the corresponding n relays are not required.

As an illustration of the use of this rule, the following table of combinations describes conditions of closure for a certain network:

	A	B	C	D
1.	0	1	0	1
2.	0	1	1	1
3.	0	1	1	0
4.	0	1	0	0
5.	0	0	1	0
6.	1	0	1	0
7.	1	1	1	0

In rows 1, 2, 3, and 4, (A) and (B) are identical, but (C) and (D) take on all possible combinations (m = 4, n = 2, $2^n = 4$). Rows 1, 2, 3, and 4, then, indicate 2^n combinations of m = 4 variables where all but n = 2 of these variables are identical. Thus, contacts on the n relays (C) and (D) are not required for these four combinations. Likewise, in rows 3, 5, 6, and 7, the variables (C) and (D) are identical and contacts on (A) and (B) are unnecessary in these rows. Now all rows have been considered. The desired circuit fulfilling all requirements of the seven combinations is expressed by

$$(A + B')\ (C' + D)$$

Another example representing six conditions for network closure follows. In this example the reference numbers over the Boolean expressions indicate the combinations from which these factors were obtained:

	A	B	C	D			
1.	0	1	0	1			
2.	0	1	1	1	3-4-5-6	1-2	2-3
3.	0	1	1	0	$= (C' + D)$	$(A + B' + D')$	$(A + B' + C')$
4.	0	0	1	0			
5.	1	0	1	0			
6.	1	1	1	0			

$$(C' + D)\ (A + B' + D')\ (A + B' + C') = (C' + D)\ (A + B' + C'D') \qquad (3b)$$

$$= (C'D' + D)\ (A + B' + C'D') \qquad (14b)$$

$$= (C'D' + D)(A + B') \qquad (3b)$$

$C'D' + D\,(A + B')$

Each row may be combined with others as many times as desired but each row must be considered at least once.

Referring again to Figure 15-30, it is apparent that if the total number of possible combinations (2^n) is divided into two parts, the circuit symbolized by one part is the negative of that symbolized by the second part. Therefore, if a network is closed for certain combinations of controlling relays, the negative of that network is closed for all remaining combinations, a corollary of the definition of the negative of a network.

This rule can be utilized in the simplification of two-terminal networks which are closed for a majority of the controlling relay combinations. To illustrate, consider a network closed for the first seven of the eight combinations of Figure 15-30. This network can be simplified as already explained:

	A	B	C			
1.	1	1	1			
2.	1	0	1			
3.	1	1	0	1-2-3-4	5-6	7
4.	1	0	0 =	(A')	(A + C')	(A + B' + C)
5.	0	1	1			
6.	0	0	0			
7.	0	1	0			

The Boolean expression may be further reduced. However, more convenient than the above manipulation is to note that the one unused combination for relays (A), (B), and (C) is

8. 0 0 0 = A + B + C

The negative of this is A'B'C' which, by the rule, is equivalent to the other seven possible combinations. This may be verified by showing that

$$A'B'C' = (A')\ (A + C')\ (A + B' + C)$$

The practical utility of the columnar notation will be shown in succeeding chapters.

15.16 APPENDIX A—THEOREMS OF BOOLEAN ALGEBRA

Addition and Multiplication

(1a) $X + Y = Y + X$
(1b) $XY = YX$
(2a) $X + Y + Z = (X + Y) + Z = X + (Y + Z)$
(2b) $XYZ = (XY)Z = X(YZ)$
(3a) $X(Y + Z) = XY + XZ$

(3b) $X + YZ = (X + Y)(X + Z)$

(4a) $X + X = X$

(4b) $XX = X$

(5a) $X + XY = X$

(5b) $X(X + Y) = X$

Negatives

(6a) $(X)' = X'$

(6b) $(X')' = X$

(7a) $(X + Y + Z \ldots .)' = X' \cdot Y' \cdot Z' \ldots .$

(7b) $(X \cdot Y \cdot Z \ldots .)' = X' + Y' + Z' \ldots .$

0 and 1

(8a) $X' + X = 1$

(8b) $X'X = 0$

(9a) $0 + X = X$

(9b) $1 \cdot X = X$

(10a) $1 + X = 1$

(10b) $0 \cdot X = 0$

Supplementary Theorems

(11a) $(X + Y)(X' + Z)(Y + Z) = (X + Y)(X' + Z)$

(11b) $XZ + X'Y + YZ = XZ + X'Y$

(12) $(X + Y)(X' + Z) = XZ + X'Y$

(13a) $f(X) = Af(X)_{A = 1,\ A' = 0} + A'f(X)_{A = 0,\ A' = 1}$

(13b) $f(X) = [A + f(X)_{A = 0,\ A' = 1}][A' + f(X)_{A = 1,\ A' = 0}]$

(14a) $XY = (X + Y')Y$

(14b) $X + Y = XY' + Y$

CHAPTER 16

DESIGN OF COMBINATIONAL RELAY CIRCUITS

16.1 GENERAL

The design procedure for a relay circuit may be divided roughly into three parts:

(1) A careful analysis of what the circuit must accomplish and what is available for the control of the circuit. This analysis will include a determination of the number of input and output leads, the nature of signals or conditions established on these leads, and the time sequence of the various input and output signals.

(2) The development of a scheme or plan of operation, which will include a determination of the number of relays and a plan of time sequence for the action of these relays.

(3) The detailed design of contact networks and circuit arrangements for receiving the input signals, controlling the relays, and establishing the desired output conditions.

During the design of a practical circuit there is often considerable overlapping of the work classified under these three headings. The work under (2) and (3) may indicate that additional input conditions are necessary or desirable, while the detailed work under (3) often indicates modifications of the plan developed under (2) which will produce a more satisfactory circuit. Due to the fact that in the design of switching circuits there are always a number of alternative ways in which a particular result may be accomplished, experience, good judgment, and ingenuity are necessary factors in the design of such circuits.

In this and following chapters, design procedures for the basic classes of relay circuits will be outlined in some detail. Emphasis will be placed on the work indicated in (2) and (3) above; the work of part (1) will be assumed completed, since it is often determined: (a) by factors over which the designer has little control; or (b) by engineering judgments based on knowledge of the general requirements of a particular system and capabilities of particular apparatus.

Knowledge of switching algebra as presented in Chapter 15 is assumed, and this algebra will be used frequently in simplifying networks and describing circuit paths. As is customary in presenting algebraic equations, a reference number near the margin of the page is assigned to each group of equations.

16.2 INPUT AND OUTPUT CONDITIONS

As defined in Chapter 13, the term "relay circuit" is an elastic term used to group together those relays we consider as a unit. By its nature, a relay circuit must be controlled and exercise control over leads connected to other circuits and apparatus. Usually, but not always, the incoming control conditions are carried by leads separate from those carrying the output conditions.

The input conditions which control the operation of a relay circuit may take a variety of forms. The simplest example of an input condition is ground applied to a single lead by some outside device for the purpose of operating a relay in the circuit under consideration. As another example, several independent input conditions may make joint use of leads, thus requiring polar or marginal relays to detect them. It is up to the individual designer to analyze a particular case to determine what shall be considered as an independent input condition in the spirit of the above examples.

An input condition is either present or absent, just as a relay is either operated or released. Each input condition whatever its nature may be, therefore, can be under the control of a single relay in an external circuit. If, now, the circuit boundary were to be extended to include these single external relays, then each resultant input condition would consist of ground on the direct path operating these new relays. The resulting circuit would perform the same action and would differ from the first only by the means used to detect the presence of the input conditions. In this chapter, we will consider each input condition as consisting of ground on a single lead; the presence of more complicated input conditions should offer no difficulty once the design fundamentals have been grasped.

Output conditions are of the same nature as input conditions with the distinction that the latter initiate action in the circuit under consideration, while the former control or pass information to other circuits.

16.3 GENERAL TYPES OF RELAY CIRCUITS

Relay circuits can be divided into three general types. In the first, the combinational circuit, a combination of input conditions, establishes a definite combination of output conditions independent of the order in which the input conditions were applied. In the second, the sequential circuit, the time sequence in which input conditions are applied affects the output conditions established. In the third, the positional circuit, the circuit location of the input leads and the time sequence of applying input conditions, both affect the combination of output conditions that are established.

This chapter will be devoted to the design fundamentals of the first or combinational type of relay circuits.

16.4 CAPABILITIES OF COMBINATIONAL CIRCUITS

As seen in Chapter 15, the total number of combinations of operated and unoperated relays (referred to hereafter as relay combinations) in a group of n

relays is 2^n. Since an input condition is either present or absent just as a relay is either operated or released, there are 2^n possible combinations of input conditions (input combinations) possible from a group of n conditions. Note that this number includes the combination of no input condition present. As we are considering an input condition per lead controlling one relay per lead, it is apparent that there will be a one-to-one correspondence of input combinations to relay combinations up to a maximum 2^n.

Since there are 2^n possible relay combinations, there are a maximum of 2^n possible independent output combinations. Consider, for example, a circuit comprising two relays (A) and (B). This circuit may, at any instant, rest in one of four states: (A) and (B) both operated, (A) operated and (B) released, (A) released and (B) operated, (A) and (B) both released. There are also a maximum of 2^2, or four, independent and mutually exclusive output combinations, each corresponding to one of the possible relay combinations. These outputs may be represented by the expressions: A+B, A+B', A'+B, and A'+B', respectively.

However, these independent output combinations do not include all the output <u>conditions</u> possible. That is, one output lead might be grounded as indicated by the expression (A+B)(A+B'), providing one output condition; another lead might be grounded for (A+B')(A'+B), providing a second output condition, and so on. These sample output conditions represent <u>combinations</u> of the original mutually exclusive output combinations. The four independent output combinations may be grouped together as 2^4, or 16, different output <u>conditions</u>. Figure 16-1 tabulates the 16 output conditions and indicates their dependence upon the operated relay combinations. The term "output condition," then, admits of a combination of independent output combinations. Since there are 2^n independent output combinations, where n is the number of relays in the circuit, the maximum number of output conditions is 2^{2^n}. The table of Figure 16-1 shows that two of these conditions are trivial in importance: (a) all combinations taken together, corresponding to a path which is always closed, and, (b) no combinations used, which represents a path that is always open. If these two output conditions are neglected, the maximum number of usable output conditions that can be established by a combinational circuit of n relays is $(2^{2^n}-2)$.

It should be noted that this expression infers that each relay of the circuit in question is equipped with an unlimited number of contacts. In practice, of course, this is not true. Thus, for a circuit of greater than two or three relays, the theoretical figure of a maximum of $(2^{2^n}-2)$ output conditions is not realizable physically.

Another method of determining all possible output conditions for a given set of relays is to derive all the unique contact networks which can be constructed on the relays of a given circuit. Again taking a circuit of two relays (A) and (B) as an example, there are the following four possible contact networks which utilize a <u>single</u> relay: A, B, A', and B'. Then, a contact on one relay may be connected in series with a contact on the other relay, resulting in four more networks: A+B, A+B', A'+B, and A'+B'. Four additional configurations are obtained by connecting

Possible Output Conditions - All Combinations of Independent Output Combinations	Corresponding Operated Relay Combinations—Two relays (A) and (B)			
	(A) and (B)	(A) Alone	(B) Alone	None
A+B	*			
A+B'		*		
A'+B			*	
A'+B'				*
(A+B)(A+B')	*	*		
(A+B)(A'+B)	*		*	
(A+B)(A'+B')	*			*
(A+B')(A'+B)		*	*	
(A+B')(A'+B')		*		*
(A'+B)(A'+B')			*	*
(A+B)(A+B')(A'+B)	*	*	*	
(A+B)(A+B')(A'+B')	*	*		*
(A+B)(A'+B)(A'+B')	*		*	*
(A+B')(A'+B)(A'+B')		*	*	*
(A+B)(A+B')(A'+B)(A'+B')	*	*	*	*
No Combinations				

Figure 16-1 Table of Possible Output Conditions for a Two-Relay Combinational Circuit. Stars Relate Output Conditions With the Initiating Relay Combinations

a contact on one relay in parallel with a contact on the other: AB, AB', A'B, and A'B'. The two symmetric networks,* (A+B)(A'+B') and (A+B')(A'+B), are two more possible network paths. Finally, the always closed path or the always open path (of trivial importance) bring the total number of networks which can be arranged on two relays, or the number of possible output conditions, to 16, as determined earlier. To illustrate the equivalence of the two methods, Figure 16-2 tabulates the possible networks on (A) and (B) and shows each to correspond to one of the combinations of relay combinations listed in Figure 16-1.

The number of possible output conditions from a given set of relays is so large that it is seldom necessary to compute them to make sure that a circuit will have enough relays to satisfy output requirements. Independent output combinations, on the other hand, may often be a determining factor of the number of relays in the circuit. For example, if twenty independent output combinations are required, at least five relays, and hence five input conditions, will be needed. In another case, if a circuit is required to start from an inactive condition and provide eight active independent output combinations, three relays with their maximum of eight combinations would not suffice since one more relay combination is needed to take care of the inactive output combination.

*Symmetric networks are discussed in Chapter 14.

All Possible Contact Networks		Corresponding Combinations of Relay Combinations
A	=	(A+B)(A+B')
B	=	(A+B)(A'+B)
A'	=	(A'+B)(A'+B')
B'	=	(A+B')(A'+B')
A+B	=	(A+B)
A+B'	=	(A+B')
A'+B	=	(A'+B)
A'+B'	=	(A'+B')
AB	=	(A+B)(A+B')(A'+B)
AB'	=	(A+B)(A+B')(A'+B')
A'B	=	(A+B)(A'+B)(A'+B')
A'B'	=	(A+B')(A'+B)(A'+B')
(A+B)(A'+B')	=	(A+B)(A'+B')
(A+B')(A'+B)	=	(A+B')(A'+B)
Always open path	=	No combinations
Always closed path	=	(A+B)(A+B')(A'+B)(A'+B')

Figure 16-2 Table of All Possible Contact Networks Which Can Be Arranged on Two Relays and the Equivalent Output Conditions

16.5 COMBINATIONAL CIRCUITS WITH SIMPLE OUTPUT CONDITIONS

The simplest form of combinational circuit from the standpoint of output conditions is one in which each output combination consists of a ground on a single separate lead and all possible output combinations are used. An example of such a circuit is the "tree" which was discussed in Chapter 14 and is reproduced here as Figure 16-3. Input conditions appear on the operating leads for relays (A), (B), (C), and (D). For four relays there are 2^4, or 16 possible relay combinations, and the 16 output combinations corresponding to these relay combinations appear, one per lead, on the output leads. No output corresponds to a combination of two or more relay combinations.

However, it is not often that the fully developed tree is necessary to satisfy the output requirements. The requirements may specify that each output lead be grounded for only one particular relay combination, but the total number of such output leads needed is less than the number of possible relay combinations. Such a set of requirements is as follows:

Input Loads Grounded	Output Loads Grounded
b	s
b,c	t
a	u
a,b	v
a,b,c	w
c	none
a,c	none
none	none

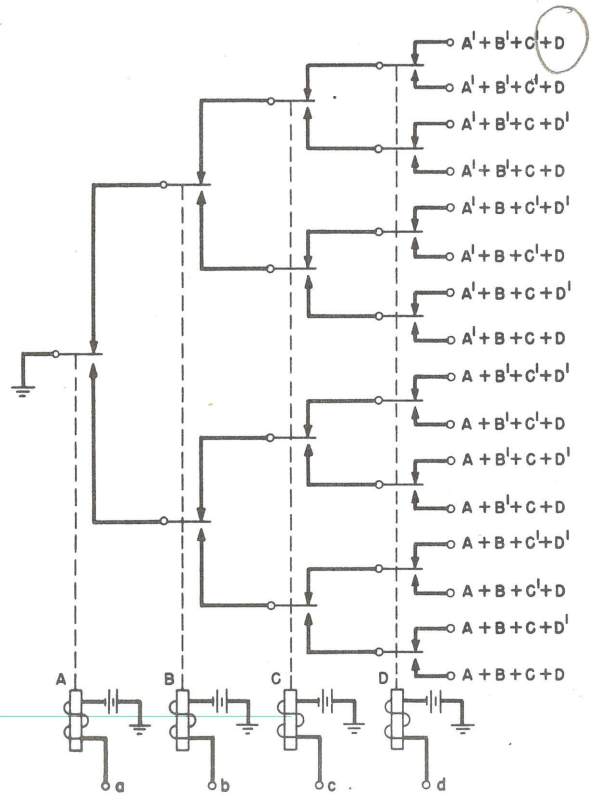


Figure 16-3 A Fully-Developed Four-Relay Tree

Regardless of whether all the relay combinations are needed or not, the technique of designing a combinational circuit entails consideration of each desired output condition and the determination of the associated requisite input conditions. That is, the circuit is synthesized from the output end. To illustrate this technique, the Boolean equation for each of the above output conditions is written from a consideration of the requirements, assuming a relay corresponding to each input lead:

$$\begin{aligned} f(s) &= A' + B + C' \\ f(t) &= A' + B + C \\ f(u) &= A + B' + C' \\ f(v) &= A + B + C' \\ f(w) &= A + B + C \end{aligned} \qquad (16\text{-}1)$$

These simultaneous equations, and their corresponding contact networks, may be combined by inspection to give the circuit of Figure 16-4. The resultant circuit is a partially developed tree, each output being disjunctive with respect to any other.

If the requirement that ground be applied to a single output lead per input combination is made less rigid, a simplification of the basic tree is often possible. When it is known that unused relay combinations will never occur, or that output conditions are inconsequential for some relay combinations, these unused or inconsequential relay combinations can be used to eliminate contacts in the circuit. The tabular notation and method of simplification introduced in Chapter 15 offer a direct approach to the simplification of the network of such circuit. For illustration, let us modify the requirements satisfied by the circuit of Figure 16-4 by stating that the input combination c, ac, and "no input grounded" never occur. The table is then drawn up as follows:

	A	B	C	Output Lead Grounded
1.	1	0	1	s
2.	1	0	0	t
3.	0	1	1	u
4.	0	0	1	v
5.	0	0	0	w
6.	1	1	1	)
7.	1	1	0	) These combinations never occur.
8.	0	1	0	)

Since the combinations represented by lines 6, 7 and 8 of the above table never occur, these combinations can be used for contact network simplification in the following manner. Considering the network for output lead u, we can allow u to be grounded not only for the active condition represented by line 3 but also for the never-occurring conditions of lines 6, 7, and 8. Taking these lines together, then, it is evident that A and C occur in all possible combinations with the result that f(u) = B'. Considering lines 1 and 6, B can be eliminated from the expression for f(s). Similarly, by combining lines 2 and 7, and 5 and 8, B is eliminated from f(t) and f(w), respectively. The algebraic notations for grounding the output leads then become:

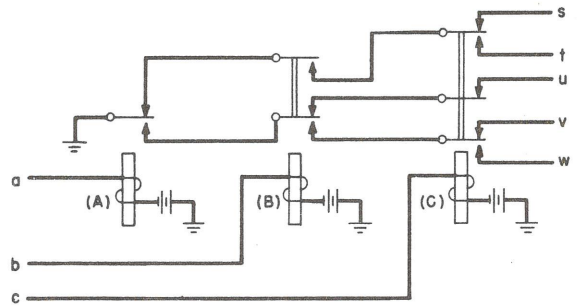


Figure 16-4 Partially Developed Tree

$$
\begin{aligned}
f(s) &= A' + C' \\
f(t) &= A' + C \\
f(u) &= B' \\
f(v) &= A + B + C' \\
f(w) &= A + C
\end{aligned}
\qquad (16\text{-}2)
$$

Comparison of equations (16-2) with (16-1) indicates the utility of the unused combinations.

Combining paths and grouping contacts with their relay windings gives the circuit of Figure 16-5. However, in retrospect it would appear that the network for f(u) has been simplified to a point where it cannot be easily combined with the other paths. If f(u) is left unsimplified, f(u) = A + B' + C', it can be combined conveniently with f(v) = A + B + C' and the further simplification of Figure 16-6 results. The point at which advantageous simplification becomes over-simplification depends upon each individual case; only experience can teach the designer to recognize when it has been reached.

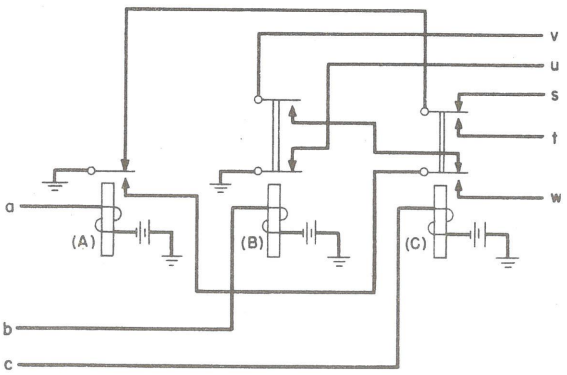


Figure 16-5 Modified Tree

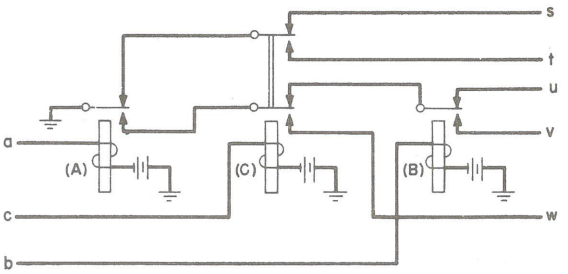


Figure 16-6 Modified Tree

16.6 COMBINATIONAL CIRCUITS WITH MULTI-OUTPUT COMBINATIONS

A frequently used type of combinational circuit is one in which several input and several output leads are grounded in combinations. To obtain a circuit to fit these requirements, as before, a relay is provided for each input condition. The paths by which each output lead is grounded are written algebraically, passing through a contact on every relay. All paths are then placed in parallel and the contact network is combined and simplified.

For example, the following is required:

	Input Leads Grounded	Output Leads Grounded
1.	a	w, z
2.	b	w, x
3.	c	w, y
4.	a, b	x, z
5.	a, c	y, z
6.	b, c	x, y
7.	none	none
8.	a, b, c	none

Note that although lines 7 and 8 in this table of requirements represent combinations which have no corresponding outputs, these input combinations do occur and hence cannot be used in simplifying the networks for the positive output conditions.

Let it also be a stated requirement that no output lead is to be connected to another for any output combination except that for which both are grounded. The contact network paths may then be written as below:

$$\begin{aligned} f(w) &= (A+B'+C')\ (A'+B+C')\ (A'+B'+C) \\ f(x) &= (A'+B+C')\ (A+B+C')\ \ (A'+B+C) \\ f(y) &= (A'+B'+C)\ (A+B'+C)\ \ (A'+B+C) \\ f(z) &= (A+B'+C')\ (A+B+C')\ \ (A+B'+C) \end{aligned} \qquad (16\text{-}3)$$

Simplifying the expression for each function:

$$\begin{aligned} f(w) &= (A+B'+C')\ [A'+(B+C')\ (B'+C)] \\ f(x) &= B + A'C' \\ f(v) &= C + A'B' \\ f(z) &= A+B'C' \end{aligned} \qquad (16\text{-}4)$$

The network paths corresponding to the simultaneous equations (16-4) are illustrated in Figure 16-7.

If the expression for f(w) is manipulated in accordance with the Boolean algebra, some simplification in the contact network can be obtained. Carrying out this manipulation:

$$\begin{aligned} f(w) &= [(B+C')\ (B'+C)+A']\ [A+B'+C'] \\ &= (B'C'+BC+A')\ (A'C'+B'+A) \\ &\quad \text{since } (B+C')\ (B'+C) = B'C'+BC \text{ and } A+C' = A+A'C' \end{aligned} \qquad (16\text{-}5)$$

Now f(w) and f(x) both contain the expression A'C' and f(w) and f(z) contain B'C'. The resultant network path diagram is shown in Figure 16-8 and the final circuit, with contacts substituted for the symbolic notation, appears in Figure 16-9. This final circuit is, of course, not the only one which might be derived, since the algebraic equation might be manipulated in some other manner. A different circuit, however, would produce the same output results.

Recalling the theorem of switching algebra stating that x+y = x+x'y, there is a temptation to obtain an even more simplified network by expanding the equation (16-4) as follows:

$$
\begin{aligned}
f(x) &= A'C'+B = A'B'C'+B \\
f(y) &= A'B'+C = A'B'C'+C \\
f(z) &= B'C'+A = A'B'C'+A \\
f(w) &= (A+B'+C')\ (A'+B+C')\ (A'+B'+C)
\end{aligned}
\qquad (16\text{-}6)
$$

Then, since f(x), f(y) and f(z) all contain A'B'C', the three are combined and the network paths appear as in Figure 16-10 and the final circuit as in Figure 16-11.

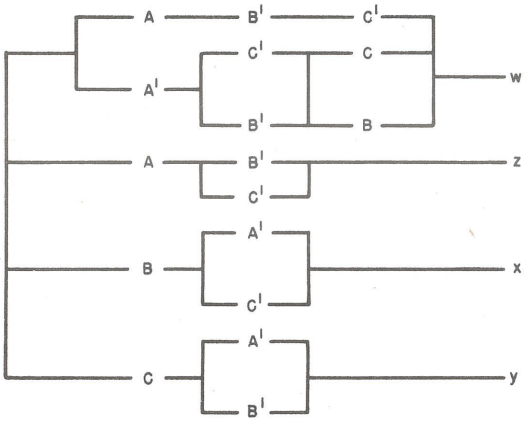


Figure 16-7 Combining Equation 16-4.

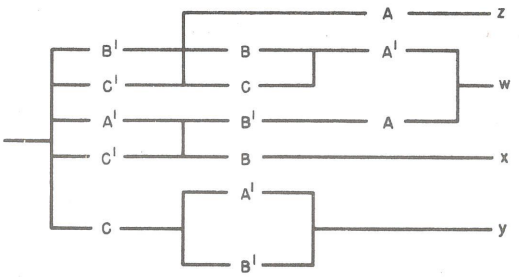


Figure 16-8 Figure 16-7 Combined and Simplified

However, inspection of Figure 16-11 shows that the output paths are not disjunctive as required, since when relays (A), (B), and (C) are operated, output leads x, y, and z are connected together but not to ground. If the original requirements can be modified to allow this circuit condition to exist, the circuit of Figure 16-11 represents a saving over that of Figure 16-9 due to substitution of a transfer contact in place of two break contacts and a make contact.

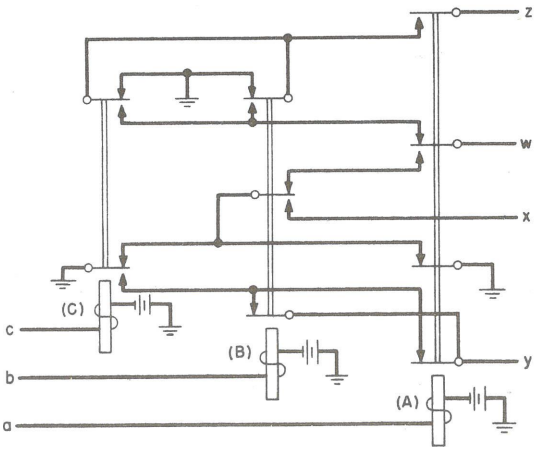


Figure 16-9 Combinations of Outputs. The Relay Circuit Symbolized by Figure 16-8

Unfortunately, there is no easily applied rule for determining whether or not the network paths are remaining disjunctive during the simplification of a combinational circuit. The final circuit must be inspected for paths not permitted by the original requirements.

As was the case with the example of paragraph 16.5, a further simplification will usually result if unused input combinations never occur or, if they do, any output condition is permissible. The algebraic expressions may be written as before but including unused paths. If the requirements stated at the beginning of this section are amended to allow inputs "none" and "a, b, c" to establish any output condition when they occur, the resultant algebraic expression can be written as follows, with the changes underscored:

$$
\begin{aligned}
f(w) &= (A+B'+C')\ (A'+B+C')\ (A'+B'+C)\ \underline{(A'+B'+C')\ (A+B+C)} \\
&= (B'+C')\ (A'+C')\ (A'+B') = A'B'+A'C'+B'C' \\
f(x) &= (A'+B+C')\ (A+B+C')\ (A'+B+C)\ \underline{(A+B+C)} \\
&= B \qquad (16\text{-}7) \\
f(y) &= (A'+B'+C)\ (A'+B+C)\ (A+B'+C)\ \underline{(A+B+C)} \\
&= C \\
f(z) &= (A+B'+C')\ (A+B+C')\ (A+B'+C)\ \underline{(A+B+C)} \\
&= A
\end{aligned}
$$

The arrangement of paths and the final circuit are shown in Figures 16-12A and 16-12B.

16.7 COMBINATIONAL CIRCUITS WITH UNGROUNDED OUTPUT CONDITIONS

The type of combinational circuit requiring the most contacts is that involving output conditions of connecting separate leads together. Simplification

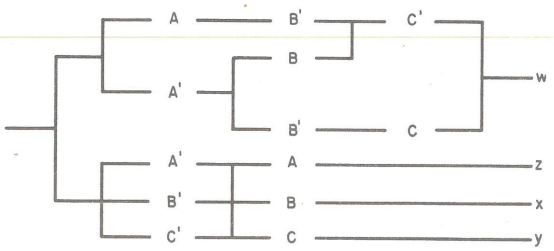


Figure 16-10 Combining Equation 16-6

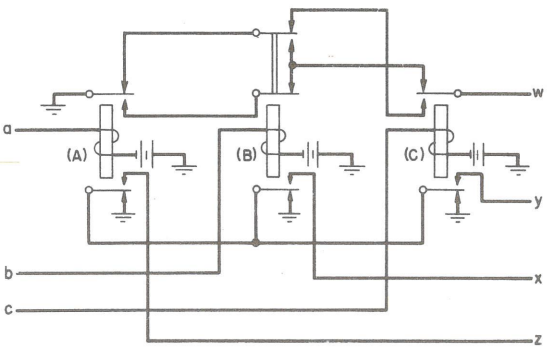


Figure 16-11 Modification of Figure 16-9

is sometimes possible, but the necessity of keeping paths separate requires many contacts. As an example take the following requirements:

Input Leads Grounded	Output Conditions
	Connect lead
none	s to t
a	u to v
b	w to x
a,b	y to z

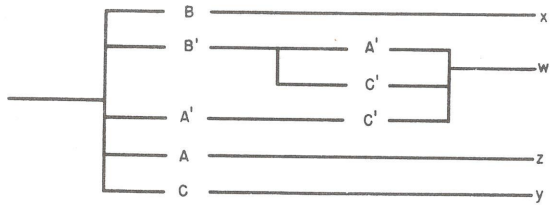
An equation is set up for each condition and the equations are inspected for the possibility of combining. In this case:

$$f(s\text{-}t) = A'+B'$$
$$f(u\text{-}v) = A+B'$$
$$f(w\text{-}x) = A'+B \qquad (16\text{-}8)$$
$$f(y\text{-}z) = A+B$$

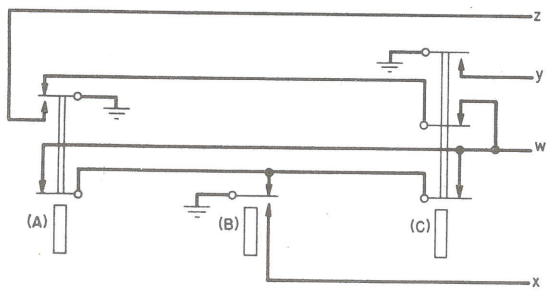
No paths can be combined and the circuit of Figure 16-13 is obtained.

16.8 COMBINATIONAL CIRCUITS WITH MANY UNUSED COMBINATIONS

Each of the circuit problems considered so far was solved by applying the symbolic method and proceeding in a definite sequence. In circuits using more than four relays, symbolic methods applied to the problem as a whole often become too cumbersome. These problems can be approached in a logical manner, however, by



COMBINING EQUATION 16-7
A



THE RELAY CIRCUIT SYMBOLIZED BY FIG. 16-12A
B

Figure 16-12 Modification of Figure 16-11

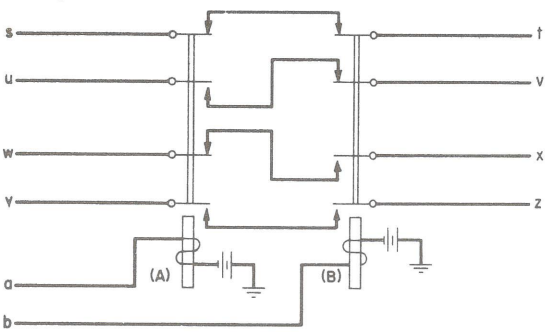


Figure 16-13 Connections as Output Conditions

observing coincidence of input and output conditions, symmetry of requirements, or other collective features. For example, take the requirements in the table below:

Input Leads Grounded	Output Leads Grounded
v,w	a
v,x	b
w,x	a,b
v,y	c
w,y	a,c
x,y	b,c
v,z	a,b,c
w,z	d
x,z	a,d
y,z	b,d

A further assumption is that no other input conditions will ever occur.

The correspondence between inputs and outputs can be used to facilitate the design of the contact network as follows:

(a) Output lead a is grounded whenever input lead w or z is grounded, except for the input combinations wz and yz. This can be stated in terms of relays controlled directly by the input leads as: Output lead a is grounded when relays (W) or (Z) are operated and not when (W) and (Z) are operated and not when (Y) and (Z) are operated. Or algebraically:

$$f(a) = WZ+(W+Z)'+(Z+Y)' = WZ+W'Z'+Z'Y' \quad (16\text{-}9)$$

(b) Lead b is grounded when (X) or (Z) is operated and not when (X) and (Z) are operated and not when (Z) and (W) are operated; that is:

$$f(b) = XZ+(X+Z)'+(Z+W)' = XZ+X'Z'+Z'W' \quad (16\text{-}10)$$

(c) Lead c is grounded when (Y) is operated and not when (Y) and (Z) are operated; or lead c is grounded when (V) and (Z) are operated; that is:

$$f(c) = [Y+(Y+Z)'](V+Z) = (V+Z)(Y+Z') \quad (16\text{-}11)$$

(d) Lead d is grounded when (Z) is operated and not when (V) and (Z) are operated; that is:

$$f(d) = Z+(V+Z)' = Z+V' \quad (16\text{-}12)$$

The combined circuit is shown in Figure 16-14.

This network could have been obtained by making a table including all twenty-two unused combinations and the combinations giving particular output conditions and combining to eliminate contacts. The work involved by this tabular method would be much longer, but if properly done, would give the same answer.

If the requirements of the above example are made more rigid and state that no output leads are to be grounded should the unused input combinations occur, advantage can be taken of the symmetry of the working input conditions. The inputs are in pairs and all possible pairs are used. By supplying ground to the contact network developed above, which assumed that other input combinations never occur, through a symmetrical circuit closed when two and only two of the five relays are operated, the more rigid requirements are met. This is shown in block form in Figure 16-15.

16.8 TEMPORARY FALSE OUTPUT CONDITIONS

In obtaining solutions to circuit problems so far, it has been assumed that a relay closed instantly when energized. Actually, of course, there is always some time delay between the instant of closing the relay's operating path and the instant of the relay closing its make contact or opening its break contact. Furthermore, there may be an appreciable stagger time between the operation of several contacts on the same relay. In addition, one relay, due to manufacturing tolerances and variations, may have appreciably different operate and release times from another similar relay. It is possible, then, that in a combinational relay circuit the wrong combination of relays will be operated for a brief time after the proper combination has been energized. Usually this time is so brief that it can be tolerated, but the designer should always be aware that it may exist and make sure that the effects of the "race condition," as this is called, are properly provided for. As an illustration of how a wrong output combination occurs momentarily in a race condition, take the input combination where output lead t is to be grounded in Figure 16-4. Suppose that output lead s is the control lead for a fast-acting relay in the connecting circuit. Input leads b and c are grounded at the same time; relay (B) being lightly loaded operates in a shorter time than relay (C) and grounds lead s. A short time later relay (C) operates, opening s and grounding lead t; but if s controls a

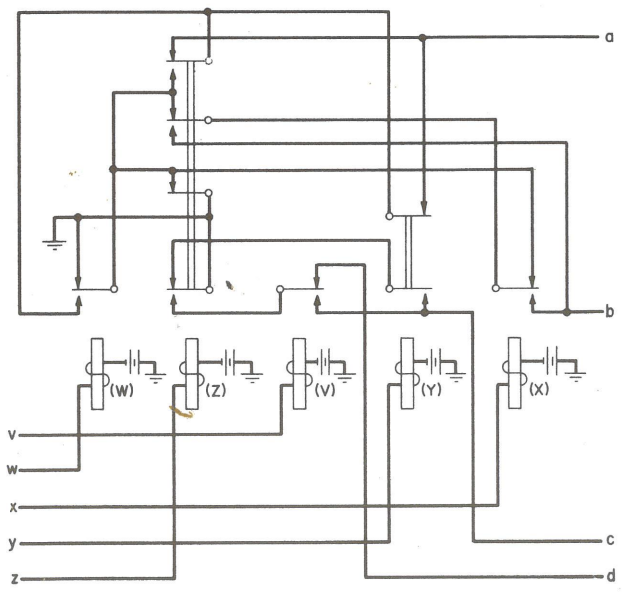


Figure 16-14 Five-Relay Combinational Circuit

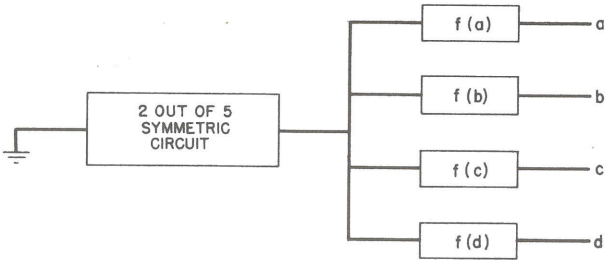


Figure 16-15 Block Diagram of Circuit Removing Ground on Unused Relay Combinations of Figure 16-14

fast-acting relay in the connecting circuit, there is a distinct possibility that this relay has already operated. Methods of guarding against such race condition when the output controls a fast-acting relay, are beyond the scope of this chapter but will be discussed more fully in Chapter 18.

CHAPTER 17

TIME CHARTS, SEQUENCE DIAGRAMS, SIMPLIFIED SCHEMATICS, AND GRAPHIC DESCRIPTIONS OF RELAY CIRCUITS

17.1 GENERAL

Anyone who has tried to understand the functioning of even a moderate size relay circuit from a schematic diagram recognizes that the task is complicated by the difficulty of following circuit paths through a large number of parallel and crossing lines. Furthermore, even if every circuit path is traced through, the dynamic action pattern of a circuit is not shown by the schematic diagram. To assist in understanding relay circuits, schematic diagrams are, therefore, supplemented by written descriptions of control paths and sequences of operation. However, even the written description has its limitations, for two or more simultaneous actions cannot be described at the same time and, with a moderately complex relay circuit, it is hard to retain in the mind a picture of what relays are operated, released, or in motion at a given instant. For this reason, use is often made of time charts and sequence diagrams of the types to be described below. These diagrams are especially useful in the initial design of switching circuits. Switching algebra in itself is a type of abbreviated notation which enables the engineer to view many circuit paths at a glance. It does not account for time sequence, however, and time sequence must often be considered as a separate factor.

In the design of sequential circuits, to be discussed in the next chapter, the time sequence in which events take place is of fundamental importance. The actual time elapsing between successive events is usually less pertinent than the relative sequence in which events take place. In designing relay control paths in sequential circuits, the chief concern is that a relay act before some and after other relays act. This is also true in the analysis of such switching circuits. Actual times, of course, must conform to requirements and must be consistent with apparatus capabilities. Also, actual time is often a major concern when a circuit is integrated with other circuits into a system.

Time charts and sequence diagrams (or charts) are a means for indicating graphically the actions taking place in a circuit, and how these actions are related to each other in time. The chief difference between these two general types is that time charts are drawn to an accurate time scale while sequence diagrams are not. Both indicate the sequence in which events occur. Time charts are used in determining the actual work time of a series of circuit actions. Sequence

diagrams are more often used in the design or analysis of switching circuits where a variable time scale permits expansion to show detail in a sequence of rapid actions.

17.2 SEQUENCE DIAGRAMS AND TABLES

Sequence can be shown in two ways. In one, the "state" type, a continuous record in chart or table form shows all pertinent input, output, and internal relay conditions as present or absent in every interval, and thus shows the combinations of relays operated at all times. The other, the "differential" type, shows only the changes of condition in their proper sequence. To determine, on the differential type diagram, the state of a circuit in any interval requires a review of the circuit action in the preceding intervals. The state type diagram, in turn, has the disadvantage that when the number of circuit elements is high, so much of the diagram is taken up by unchanging state indications that it becomes difficult to locate the changes and to follow their sequence. For this reason, the state diagram is usually used with small circuits and the differential with large ones. Indication of circuit control means can be added to either type diagram by means of additional lines or symbols. Since any additional lines will tend to make the sequence less clear, whether or not they are used will depend on the particular application.

Since no method of denoting sequence has been universally adopted, many variations in both diagrams and symbols are in use. Several representative methods will be described.

1. The first diagram to be considered is of the state type. The circuit used for illustration is shown on Figure 17-1 and the corresponding sequence diagram is on Figure 17-2. This diagram is divided into spaces of arbitrary length by vertical lines. Each vertical line represents the moment at which some action, such as the operation or release of a relay, takes place with sequence progressing from left to right. The "State" of the circuit is indicated in the space between vertical lines. (In a relay circuit the "state" is the combination of relays operated, and the action of a relay in operating or releasing changes the state.)

Relays are assigned horizontal levels and are shown operated (not necessarily energized*) by a solid line on the horizontal level or are shown released by no line on that level**. The solid line runs through all spaces during which the relay is operated. Each vertical space can be numbered for reference. Note that a space must be left between any two actions which do not occur simultaneously.

---

*A relay is "energized" when an external source of potential sufficient to cause eventual operation is applied across its winding. Some delay will always exist between this application and the building up of sufficient flux to move the armature. A relay is "operated" when make-contacts are closed and break-contacts open, and "released" when the converse is true. Thus a relay can be energized and still be in a released position immediately prior to operating, or it can be de-energized and in an operated position immediately prior to releasing.

**This is sometimes varied by designating each relay by a horizontal line. When the relay is operated the line is offset upwards by a slight amount to be returned to the original level when the relay is released.

Input conditions, output conditions, keys, and other apparatus can be each assigned to a horizontal level and their presence or operation indicated in the same manner as for a relay. To bring out the usefulness of such a sequence diagram, first a written description of the circuit in Figure 17-1 is given as follows. (This circuit is used merely for example and is not shown as performing any useful function.)

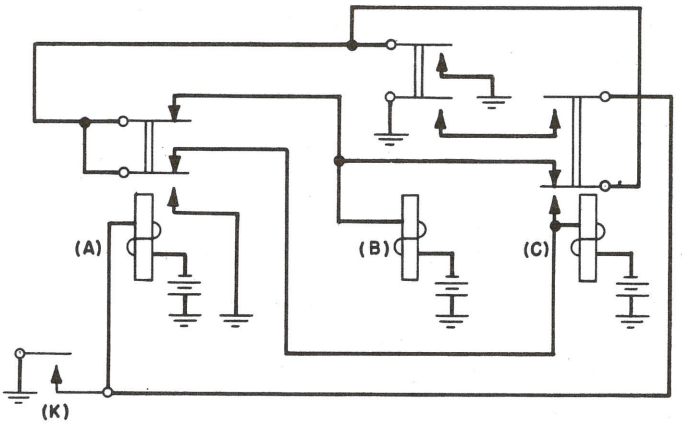


Figure 17-1 A Sequential Circuit

Closing key (K) applies ground to the winding of relay (A) operating it. Relay (A) closes the operating path (A+C'), which operates relay (B). Relay (B) locks on path (B+C'). Releasing key (K) releases relay (A). Now a path (A'+B) operates relay (C) and a second path (A'+B) holds relay (B). Relay (C) locks on path (B+C) and operates relay (A) over path (C+B). Relay (A) opens the locking path of relay (B) and holds relay (C) through path (A+C). Relay (B), releasing, releases relay (A) which in turn releases relay (C).

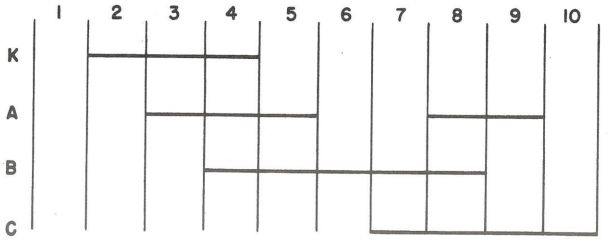


Figure 17-2 Sequence Diagram for Circuit of Figure 17-1, Using Method 1

The sequence of operations described above is more apparent when shown as on Figure 17-2, although control paths are not indicated on this diagram. Notice that interval (2) represents the operate time of relay (A); interval (3) the operate time of relay (B); interval (5) the release time of relay (A); and so forth. If controlling elements are to be identified, light arrows may be added as in Figure 17-3. These show, for example, that the operation of (K) causes the operation of (A) which, in turn, causes operation of (B) in intervals 2 and 3, respectively. This type of sequence diagram, without control arrows, will be used extensively in Chapter 18.

2. A second type of presentation of sequence is one which uses the symbols introduced in Chapter 15 for the tabulation of relay combinations. Since a circuit with relays operating in sequence is progressing through various combinations of operated and unoperated relays, the sequence can be recorded by tabulation of the combinations in the order in which they occur. In these tables time will run down the page and each relay will be given a vertical column. A relay is shown operated

by symbol 0 and unoperated by symbol 1. Action of Figure 17-1 can be expressed by this method as shown in Figure 17-4. Note that the numbered lines correspond to the numbered intervals of the diagram of Figure 17-2. The tabular sequence table will be used also in Chapter 18.

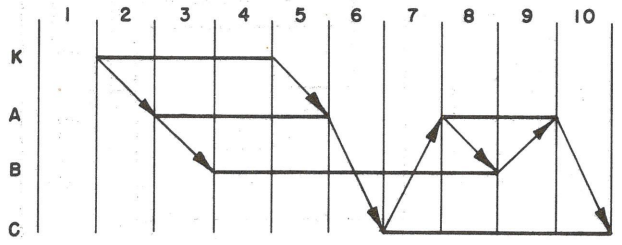


Figure 17-3 Modification of Figure 17-2 to Show Control

	K	A	B	C
1.	1	1	1	1
2.	0	1	1	1
3.	0	0	1	1
4.	0	0	0	1
5.	1	0	0	1
6.	1	1	0	1
7.	1	1	0	0
8.	1	0	0	0
9.	1	0	1	0
10.	1	1	1	0

Figure 17-4 Sequence Table

3. The third method of presenting sequence is of the differential type showing only the changes in state. As mentioned earlier, this type of diagram becomes more necessary with large numbers of relays, since each relay is indicated and occupies space on the diagram only at the time it acts. Sequence progresses downward on this diagram and actions are denoted by symbols. Relay operation is represented by "x" and release by "-" accompanied by the designation of the relay involved. If an action is responsible for a subsequent action, the dependent action is indicated directly below the first and connected to it by a vertical line. When two parallel chains of action are both necessary for one action, that action is placed directly below one chain of action and connected to it by a vertical line. Then a line is drawn diagonally to this vertical line from the bottom of the other chain of action. A comparison of Figure 17-5 and its sequence diagram of this type, Figure 17-6, will demonstrate how these symbols are used. The coordinate system of

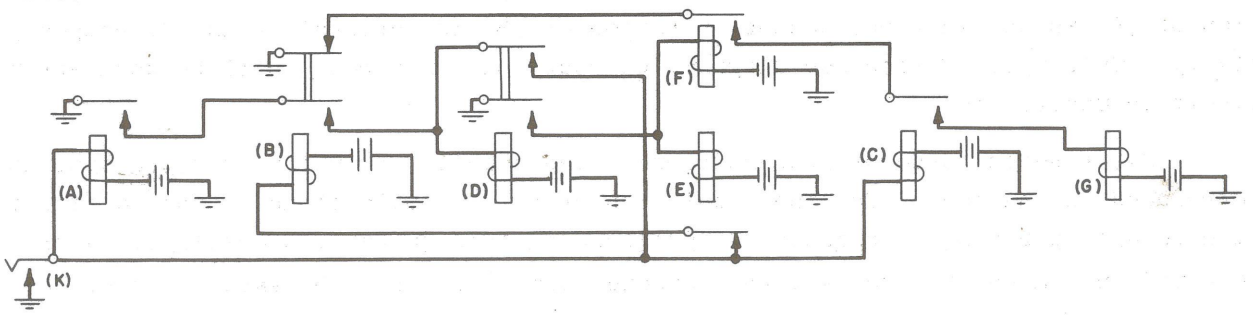


Figure 17-5 A Larger Sequential Circuit

letters and numbers included with this type of sequence diagram is for the purpose of making possible quick references. An application is shown at coordinate point M-1 where relay (C) operating is a necessary action for relay (G) to operate at Q-2.

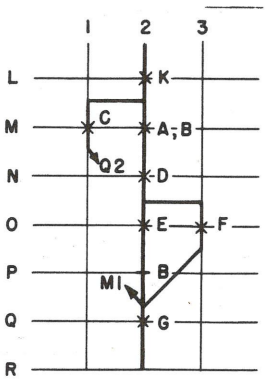


Figure 17-6 Sequence Diagram of Circuit of Figure 17-5, Using Third Method

17.3 TIME CHARTS

Very often the length of time that a circuit and certain of its components will take to operate, or the time that elapses between two of its output conditions, must be computed in order to determine how it will work in with other circuits and into the system of which it is a part. The values of the acting times of relays are usually known and the maximum, minimum, and average times may be computed for the whole or any part of the circuit operation if the corresponding numerical time values of the relays are added properly. If the action is at all complicated, however, it is much more convenient to draw a sequence diagram to a definite time scale. Thus Figure 17-2 could be redrawn to scale as in Figure 17-7, where each vertical space column represents 0.025 second. Any desired time can be easily obtained by measuring it on the diagram. For example the time between two successive operations of relay (A) is seen to be 0.290-0.050 = 0.240 second.

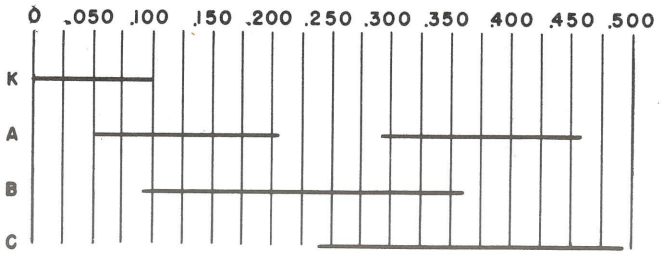


Figure 17-7 Time Chart for Circuit of Figure 17-1

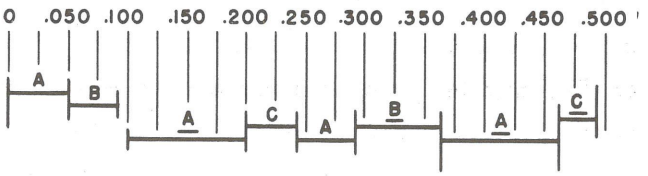


Figure 17-8 Time Chart for Circuit of Figure 17-1

A second method represents the acting time of a relay by segments of horizontal lines which are not assigned to a given horizontal level and which are shown only during the acting time. These lines are identified by the relay designation with some mark, such as an underline, to differentiate between

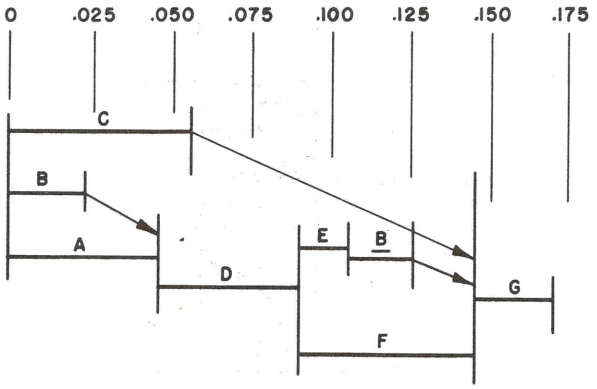


Figure 17-9 Time Chart for Circuit of Figure 17-5

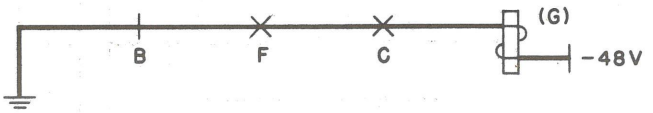


Figure 17-10 Abbreviated Notation of a Control Path

operation and release. Vertical lines denote direct control, slanting lines with arrows, indirect control. Time charts by this method for Figures 17-1 and 17-5 are shown in Figures 17-8 and 17-9 respectively.

17.4 PARTIAL SCHEMATIC DRAWINGS ON "SHORTS"

In addition to means for presenting a clear picture of sequence of relay operations, there is often a need for showing relay control paths in a manner simpler than that of a complete schematic drawing of the circuit. Usually, when only the contacts necessary for a given operation are shown, what had appeared as an involved path on the complete schematic diagram now appears as an obvious and familiar arrangement. This result, as mentioned in the opening paragraph of this chapter, may be achieved to a degree by the algebraic expression; however, where contact sequences, bridge type circuits, and relay sequences are encountered, algebra does not always produce an adequate representation. Therefore resort is made to simplified diagrams called relay "shorts." The procedure used for preparing a relay "short" is to omit from the diagram all contacts not involved in the operation under consideration, to draw out the relay control paths in order, and to disassociate relay contacts and relay windings, with, perhaps, the exception of locking contacts. Instead of drawing each contact, an "x" may be used to represent a make-contact and a " " to represent a break-contact. Relay spring numbers may be included to identify particular contacts if the diagram is to be used with actual apparatus. Figure 17-10 shows the operating path of relay (G) of Figure 17-5, drawn out in this manner. A more complicated control path is shown in Figure 17-11*.

*This type of abbreviated notation is used in the training manual for Crossbar System No. 5.

17.5 GRAPHIC DESCRIPTION OF RELAY CIRCUITS

A simple but complete representation of the action of a relay circuit is of great aid to both the designer of the circuit and to others who, for various reasons, need to learn its operation. The drawbacks of the written circuit description and schematic drawing from this standpoint have already been mentioned. The graphical sequence diagrams discussed in the first part of this chapter are useful in presenting what circuit actions take place and when they occur, but some abbreviated circuit sketches or relay shorts of the type described in paragraph 17.4 are needed to round out the presentation by showing how the actions take place. A substantially complete graphical representation of circuit operation by a combined sequence diagram and relay "short" is described in the following paragraphs.

This graphic description, whose symbolic notations are shown on Figure 17-12, makes use of a sequence diagram of the state type and is similar in this respect to the first diagram described in paragraph 17.2. As in that diagram, relays and other apparatus are assigned horizontal levels, with the state of any particular circuit component denoted by the absence or presence of a solid horizontal line at the corresponding level. Sequence progresses from left to right. (The orientation of the whole diagram with respect to horizontal and vertical may, of course, be interchanged.)

To show circuit details, control path indications are included as vertical lines in the proper sequence locations on the diagram, whenever they are opened or closed. A solid vertical line is used to denote the closure of a path and a dashed line to denote the opening of a path. The contacts making up the path are shown by symbols at the appropriate intersections of the horizontal relay levels and the vertical control path lines. The user of the diagram has available, therefore, information concerning both the over-all operation pattern and the particular causes and effects of every individual action.

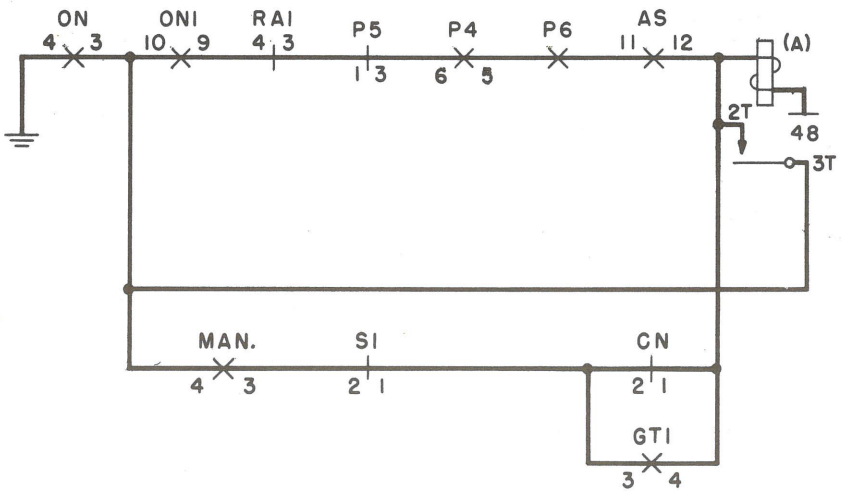


Figure 17-11 Abbreviated Notation of a More Complicated Control Path

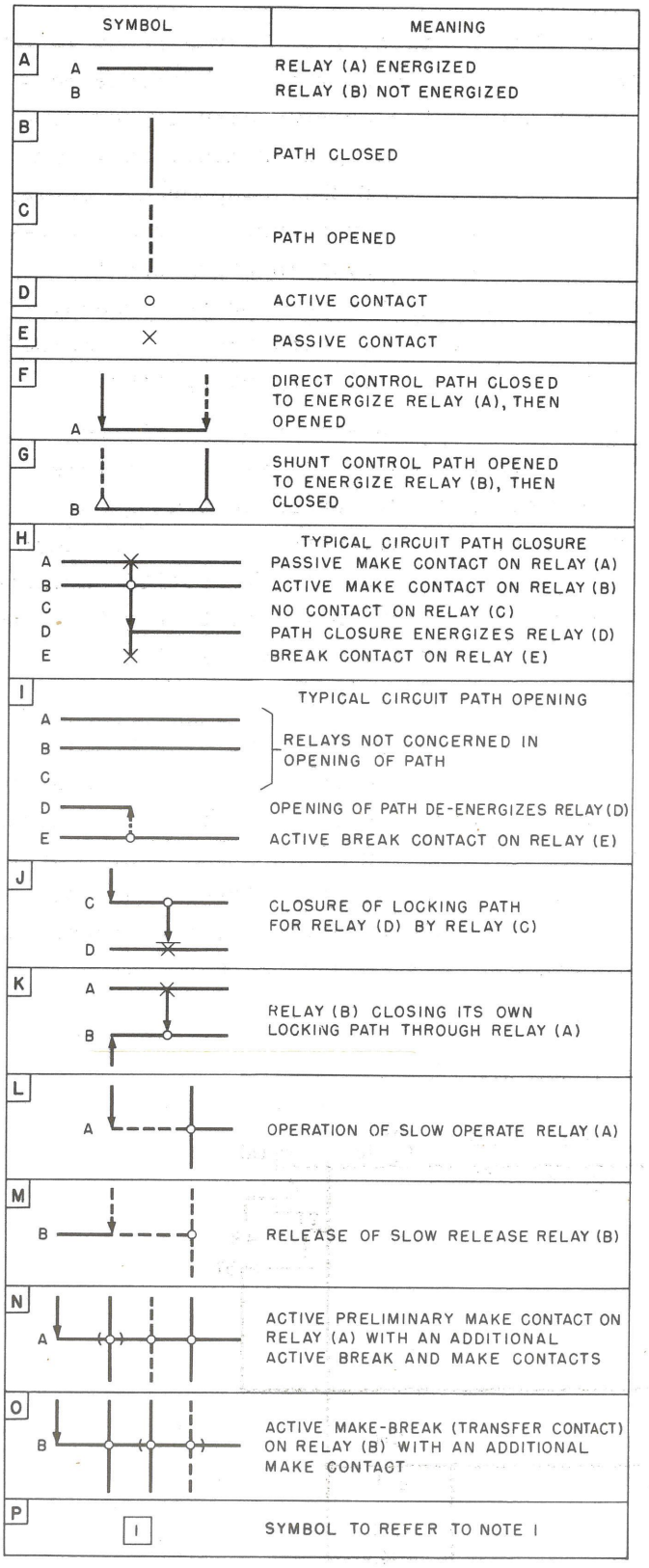


Figure 17-12 Symbols for Graphic Circuit Description

The number of symbols used has been kept as low as possible to facilitate both the construction and reading of the diagram. Figure 17-12 lists all of the common symbols. The arrowhead is used to identify the controlled circuit component. It is put on the vertical control path line at the level of the component controlled by that path. Contact symbols differentiate between active and passive contacts. The active contact, whose symbol is a small circle, is the last one to close or the first one to open a path, if a number of series contacts are involved in the path. On the other hand, the passive contacts, whose symbols are x's, are those which are necessary to complete the path, but which have been closed prior to the time at which the path is completed. A given contact may be a passive contact when a path is closed and be the active contact when the path is opened. Whether or not a contact is a make type or break type and whether or not it is opened or closed can be determined by observing the state of its associated relay and the condition of the path of which it is a part. Thus, an active contact of a relay which is shown after that relay has been released as closing a control path is evidently a break contact.

Figure 17-12H shows a typical circuit path being closed by an active contact on relay (B) and passing through passive contacts on relays (A) and (E).

Note that the solid horizontal line showing energization of relay (D) starts immediately at the arrowhead. Figure 7-12I shows the same path opened, but this figure does not need to show passive contacts since such contacts do not contribute to the path-opening operation.

Other symbols for slow relay operation, shunt paths, contact sequence, and the like, are explained in Figure 17-12. Symbols for the active contacts of a relay are always shown adjacent to each other following the change of state of the relay. Figure 17-13 shows how active contacts on two relays which are energized simultaneously are depicted. No inference is drawn concerning the sequence of action of any of the contacts on either relays (A) or (B) or (C). Since none of the specific symbols denoting contact sequence or relay speed are shown. To keep the number of symbols small, unusual circuit configurations are not covered symbolically, but in the form of circuit notes.

A difficulty with the state type of sequence diagram, which has already been mentioned, is that when the number of circuit elements is large, the diagram is cluttered up with unchanging state indications which conceal the significance of important sequences. To correct this situation, the graphic circuit description brackets those relays which remain relatively inactive for many intervals. The bracketed relays are then carried as a single state line for their inactive period, thus freeing space for the representation of other relay actions. When one or more elements within the bracketed group becomes involved in a circuit control path, it is indicated by the proper symbol on the group state line. External circuits are carried in a similar manner by single state lines*.

To conclude, a moderately extensive example of the graphic circuit description is attached as Figure 17-14, representing the operation of the circuit of Figure 17-15. The circuit itself is intended only to illustrate the graphical notation and performs no obvious function.

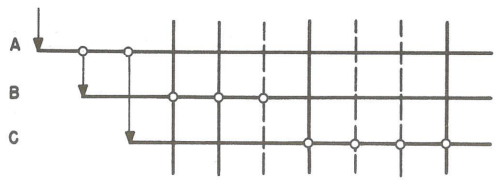


Figure 17-13 Simultaneous Relay Action

*This graphical representation is used in Section A320.665 of the Bell System Practices for SD-55954-01.

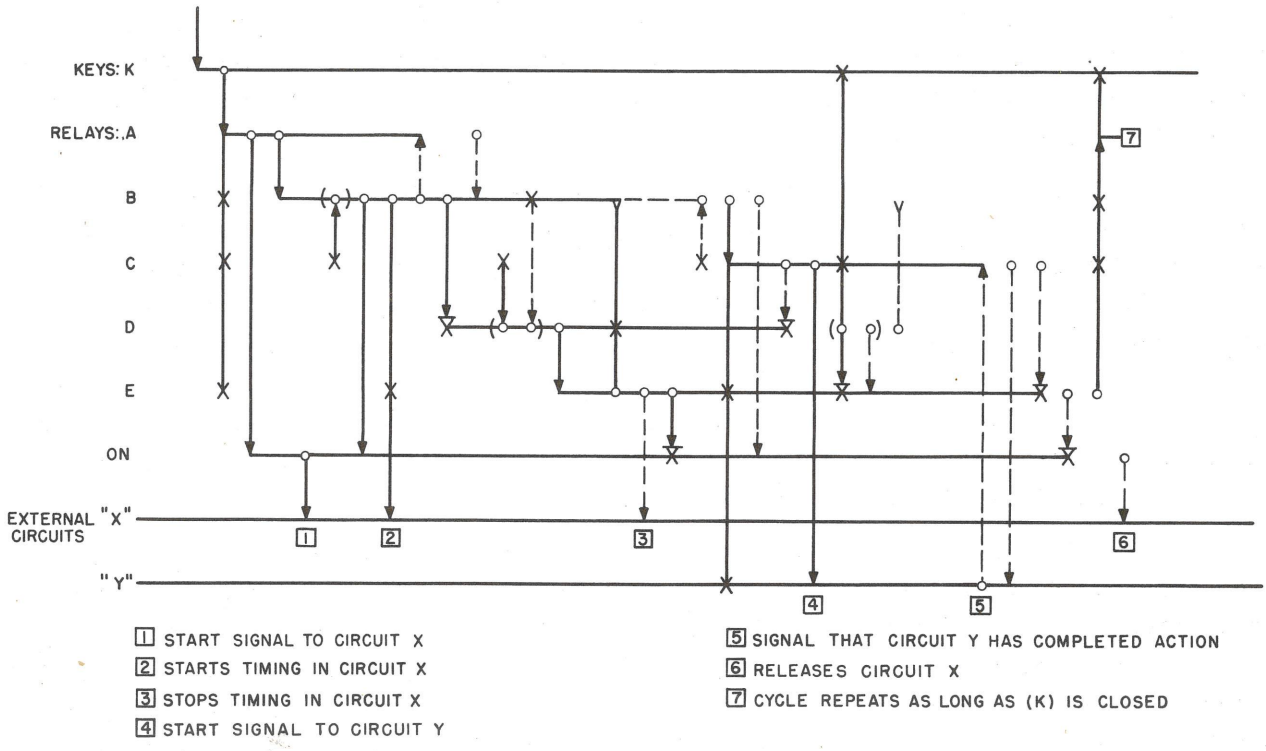


Figure 17-14 Graphical Representation of Circuit Operation of Figure 17-15

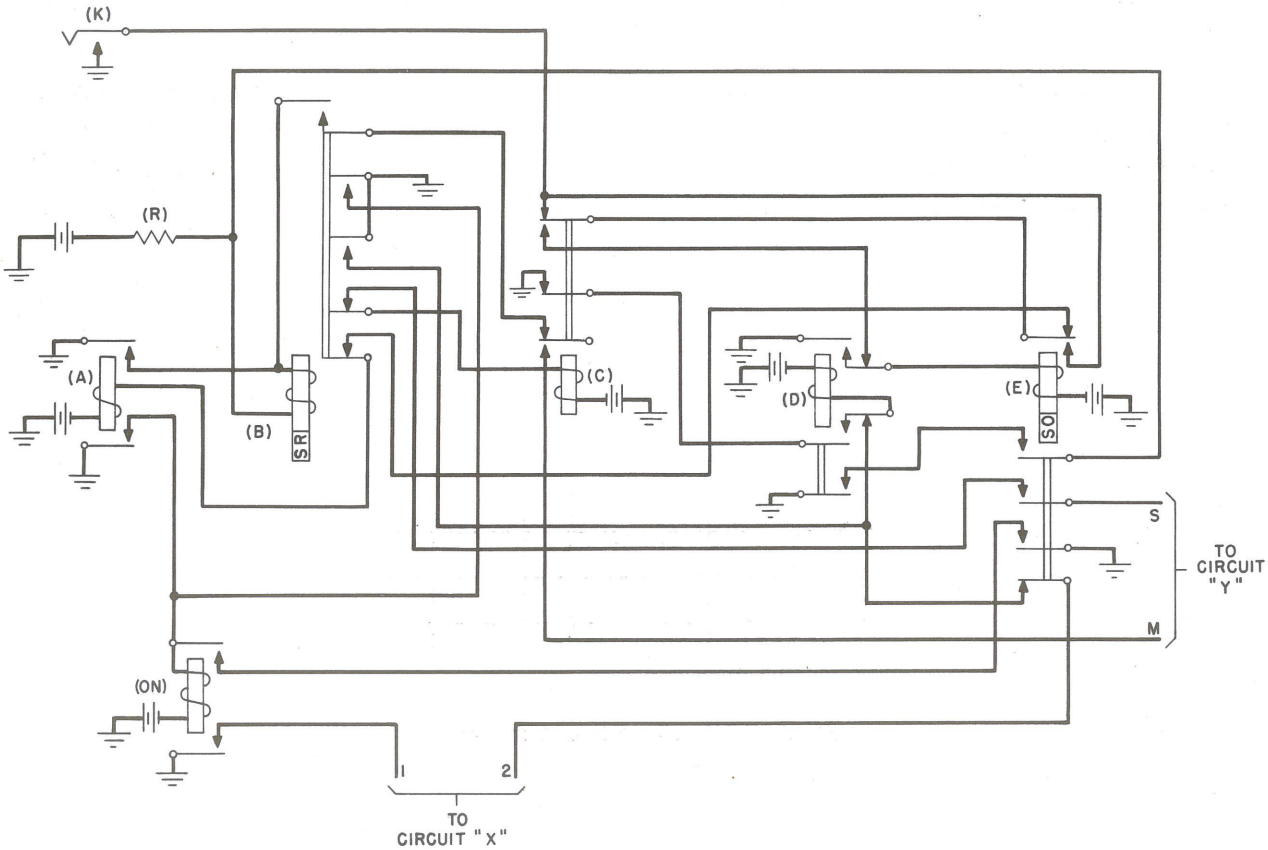


Figure 17-15 A More Complex Relay Circuit

CHAPTER 18

DESIGN OF SEQUENTIAL RELAY CIRCUITS

18.1 GENERAL

The relay circuits studied so far establish an output combination in direct response to the application of a corresponding input combination, whenever that input occurs. Frequently circuits are needed which establish output combinations determined not only by the particular input combinations applied, but also by the preceding actions of the circuit. These circuits must meet requirements of input and output combinations occurring in definite sequences and hence are called sequential circuits.

Suppose, for example, that a circuit is to control an answer lamp associated with the appearance at switchboard B of a tie trunk which connects switchboards A and B. The lamp is to be lighted when lead "a" of the trunk appearance at position A is grounded and is to be extinguished when lead "b" of the appearance at position B is grounded. These inputs correspond to the insertion of plugs into jacks at the two positions. The lamp is not to relight when the plug at B is removed before the plug at A. The sequence of these events is shown by sequence diagram in Figure 18-1. Here, the input combination of lead "a" grounded and "b" not grounded is to establish a grounded condition on lead "el," controlling the lamp on its first appearance, but is to establish no output on its second appearance. None of the circuits considered so far can provide two different output combinations for the same input combination.

To obtain the features needed in a sequential relay circuit, two groups of relays are needed which we shall call primary and secondary relays. The primary relays perform a function similar to that performed by relays in a combinational circuit, in that they detect input conditions and may establish a wide variety of circuit paths dependent on the input combinations. The secondary relays are the components which record significant actions within the circuit and later affect the outputs. In general, secondary relays are controlled by contacts on the primary relays, on other secondary relays, and on themselves. This internal control enables the designer to plan a circuit in which the combination of relays operated at any given time depends both on the applied input combination and on the previous circuit actions.

Following the design procedure outlined in paragraph 16.1, a careful study must first be made of input and output conditions, with special attention paid to

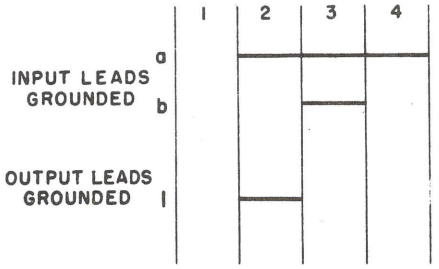


Figure 18-1 Sequence Diagram of Input and Output Conditions

the sequence of their appearance. In practice these requirements must be determined, but in this chapter, they will be given mainly by sequence diagrams or tables. The next step in design, the development of a plan of operation, requires much more study in the case of sequential circuits than it did with combinational circuits. The need for secondary relays must be determined and the order of relay operations coordinated with the sequence of the input and output requirements. The final step, that of detailed design, consists of the design of the control paths for the secondary relays and of the contact networks to provide the proper output conditions.

As with combinational circuits, all of these steps are interdependent. The choice of the relay acting sequence greatly affects the complexity of some of the contact networks. For this reason, in this chapter, appropriate sequences will first be assumed and the corresponding control and output path design will be considered. Emphasis will be placed on secondary relays in both steps since they introduce most of the design problems which cannot be handled by combinational relay circuit design methods alone.

18.2 PRIMARY RELAYS IN SEQUENTIAL CIRCUITS

The primary relays in a sequential circuit serve the purpose of detecting input combinations and producing corresponding relay combinations in the same way as the relays of a combinational relay circuit. The contacts on the primary relays can, then, provide paths opened or closed for any set of input combinations. Input conditions may require special relays, such as marginal or polar relays, to detect their presence, but for simplicity only conditions of a grounded lead to the winding of a primary relay will be considered in this chapter. A statement of input sequence will then be equivalent to a statement of the sequence of operation of the primary relays. For this reason, Figure 18-2, in which the sequence of primary relay actions is plotted, conveys the same information as Figure 18-1. Actually, of course, there is always a slight time difference between input appearance and primary relay operations, due to relay acting times.

In the cases where the delay introduced by a primary relay must be minimized, it is sometimes possible to eliminate this relay by manipulating the circuit to reduce the contacts of such a relay to a single grounded make. This make contact may then be replaced by the relay control lead and the relay omitted.

18.3 SECONDARY RELAYS IN SEQUENTIAL CIRCUITS

The secondary relays in a sequential circuit provide a record of what actions the circuit has taken and thus guide future circuit operations. As illustration, take the sequence diagram of the primary relay operations and output

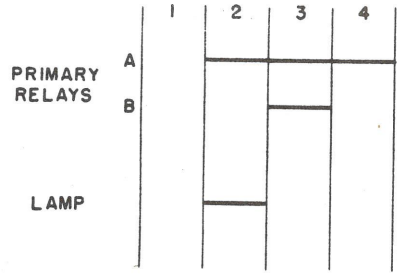


Figure 18-2 A Sequence of Primary Relay Operations

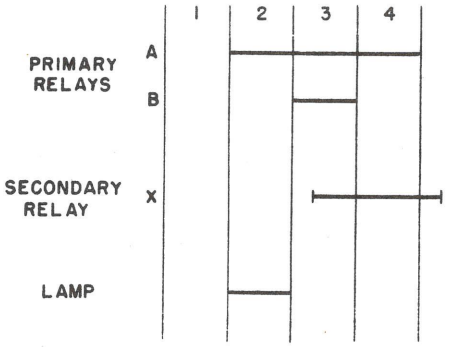


Figure 18-3 Sequence of Action of a Secondary Relay

combinations of Figure 18-2. No arrangement of contacts on relays (A) and (B) alone can provide the output condition desired in interval 2 without also providing it in interval 4, because in both intervals the same primary relays are operated. A secondary relay, however, which will be in the released position in interval 2 and in the operated position in interval 4 will provide a unique relay combination (A+B'+X'), in interval 2 which can therefore establish the output. The sequence in which the secondary relay acts is shown in Figure 18-3. The reason why the output lead is not grounded upon the reappearance of primary relay combination (A+B') in interval 4 is that relay (B) has operated relay (X) in interval 3. Relay (X) in operating records the fact that relay (B) has operated and it must hold this record through interval 4 by locking through one of its own contacts to a contact network which will release it when circuit action is completed. In this case, a make contact on relay (A) is closed throughout the necessary intervals and will serve as a holding contact. The complete circuit is shown in Figure 18-4.

18.4 CONTROL OF SECONDARY RELAYS

As mentioned previously, the control paths of secondary relays are not designed until the sequence of operation of all relays in the circuit has been decided upon. Since the sequence chosen affects the complexity of the secondary relay or internal control paths, a knowledge of the principles and design techniques of such paths is prerequisite to the planning of good operation sequences.

This section shows how internal control paths are designed. As will be seen, the requirements of these control paths are almost completely contained in the statement of the sequence of relay actions. Such a sequence is very conveniently expressed by either sequence diagrams or tables, and

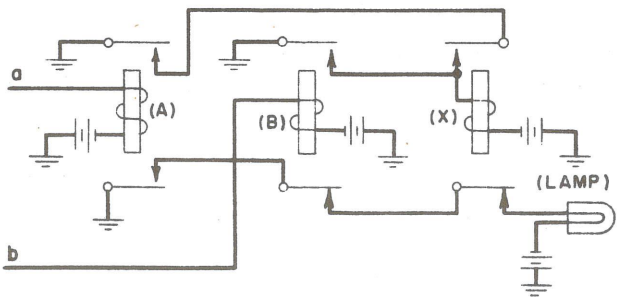


Figure 18-4 Circuit for Sequence of Figure 18-3

both the state-type of sequence diagram and the sequence table introduced in Chapter 17 will be used in this chapter.

The basic method of determining control paths can be best described by considering an example. Referring back to Figure 18-3, let us consider the internal control path of relay (X). To operate in the sequence indicated by the diagram, relay (X) must be energized as shown by the dashed line of Figure 18-5. Now, by combinational relay circuit design methods, a contact network can be designed for the three relays (A), (B), and (X) which will provide a closed path for each of the combinations for which relay (X) is to be energized. This network, used as the direct* control path of relay (X), will control it in the sequence shown in the diagram.

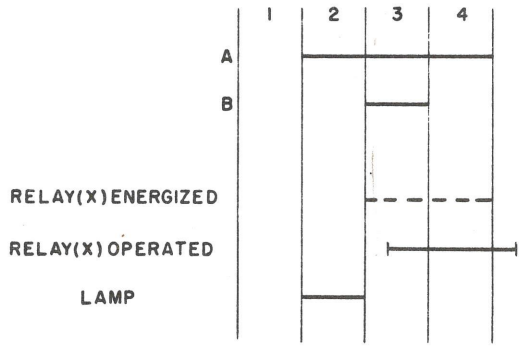


Figure 18-5 Modification of Figure 18-3 to Show Energization of Relay (X)

Note that contacts on secondary relay (X) itself must be used, since primary relay combinations in intervals 2 and 4 are identical. Taking a path for each relay combination for which (X) is to be energized and placing these paths in parallel gives:

$$f(x) = (A + B + X')(A + B + X)(A + B' + X) \quad (18\text{-}1)$$

$$= (A + B)(A + X) \quad (18\text{-}2)$$

$$= A + BX \quad (18\text{-}3)$$

The circuit is shown schematically in Figure 18-6.

As with combinational circuits, unused relay combinations may be added to achieve simplification. In this case relay combinations $(A' + B + X')$ and $(A' + B + X)$ never occur. These combine together to give $(A' + B)$ which may be combined with equation 18-2 as follows:

$$f(x) = (A + B)(A + X)(A' + B)$$

$$= B(A + X) \quad (18\text{-}4)$$

This path was shown schematically in Figure 18-4.

Algebraically, equation 18-4 is not equivalent to equation 18-3, but either contact arrangement will provide the proper control path for relay (X). When such alternate choices occur, the ease of combining with other paths usually determines which will be used.

The method used above, that of using all combinations in which the controlled relay is energized, is general and could be used to design any secondary

*Throughout this chapter we shall be primarily concerned with direct control paths and not shunt paths. Shunt paths, because of their tendency to consume more power and to slow relay actions, are generally used only to meet restrictive conditions or where they may effect appreciable savings in relays and contacts.

relay control path; however, as with the comparable method in combinational design, it becomes unwieldy where many relays and combinations are involved. Advantage can be taken of certain qualities of the secondary relay control paths to provide quicker methods of design.

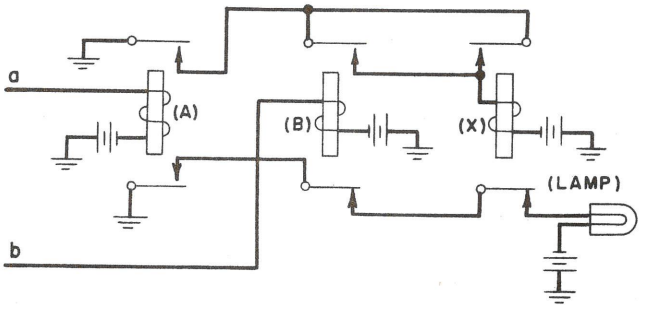


Figure 18-6 Control of Relay (X) by (A+BX)

These quicker methods involve the division of the control path into two parts. First, consider the paths through which a secondary relay (X) is first energized. Since (X) is in an unoperated position at this time, one of the contacts of this path will be X'. Let the rest of this operating path be represented by $g_1(x)$; then the expression for the whole path is $X' + g_1(x)$. This operating path will be broken when (X) moves to the operated position, so that the next path through which (X) is energized must be $X + g_1(x)$. These two paths may be combined and simplified:

$$[X' + g_1(x)][X + g_1(x)] = g_1(x) \qquad (18\text{-}5)$$

The combination of relays establishing $g_1(x)$ is an operate combination. If relay (X) operates several times, there may be several operate combinations. The parallel connection of paths closed on these combinations is the operating path, designated g(x).

Second, consider the paths through which a secondary relay (X) is held energized after it has been operated. All the relay combinations which occur during this period contain relay (X) operated, so that the several individual holding paths may be represented by $X + h_1(x)$, $X + h_2(x)$, and so forth, where $h_1(x)$, $h_2(x)$, ...represent paths closed on hold combinations for relay (X). When these paths are connected in parallel, they may be combined to give $X + [h_1(x)][h_2(x)]$.....

$$\text{Let } h(x) = [h_1(x)][h_2(x)] \ \ldots\ldots \qquad (18\text{-}6)$$

Then the combined paths may be represented by $X + h(x)$ where h(x) will be called the hold path.

A parallel connection of $X + h(x)$ and g(x) will give the complete control path of the relay:

$$f(x) = g(x)\,[X + h(x)] \qquad (18\text{-}7)$$

The basic configuration of this equation, shown in Figure 18-7, is seen to be that of the lock-up circuit introduced in Chapter 13.

Thus we see that the secondary-relay control problem can be divided into two parts, the first dealing with bringing the relay into the operated position, and the second dealing with holding it continuously operated through its own

picked which covers at least a few intervals, at the end of which another path is selected to take over, and so on up to the release interval. Caution must be observed that each hold combination determined in this manner will be open whenever the relay is to release. The parallel connection of these paths will give the hold path, usually in a simple form.

Examples will now be given to show how the above methods are used. The choice of approach is generally dependent on the complexity of the sequence and number of relays involved. Referring to Figure 18-3, g(x) in interval 3 is found to be (A+B) with simplification possible since (A' + B) does not occur.

$$g(x) = (A + B)(A' + B) = B \tag{18-8}$$

The hold combination h(x) in interval 4 is (A + B'). Combining it with g(x) for simplification purposes results in:

$$h(x) = B(A + B') = AB \tag{18-9}$$

This is using the first method for determining the hold path. With the second method, the release combination (A' + B'), which succeeds interval 4, is used, giving:

$$h(x) = (A' + B')' = AB \text{ as before} \tag{18-10}$$

Inspection, which is the third approach, indicates that (A) releasing is responsible for release of relay (X) so that (X) may be held to a make contact on relay (A) which is operated throughout the hold period. This gives:

$$h(x) = A \tag{18-11}$$

Any of the three methods, when combined in the general equation, gives:

$$f(x) = B\,(X + A) \tag{18-12}$$

or if g(x) had not been simplified:

$$f(x) = (A + B)(X + A) = A + BX \tag{18-13}$$

Either final equation is easily obtainable by any of the methods described since so few relays are involved.

Figure 18-8 shows a little more complicated sequence requiring two operations of a secondary relay (X) in intervals 2 and 7. For this sequence:

$$g(x) = (A + B' + C')(A' + B + C) \tag{18-14}$$

(first operation)(second operation)

Combination (A + B + C) does not occur so g(x) may be simplified by using this combination as follows:

$$g(x) = (A + B' + C')(A' + B + C)(A + B + C) \tag{18-15}$$
$$= (A + B' + C')(B + C)$$

The hold path in intervals 2, 3, and 8 is determined as follows:

$$h(x) = (A' + B' + C')(A' + B + C')(A' + B' + C) \tag{18-16}$$

(first operation) (second operation)

This may be simplified to:

$$h(x) = A' + B'\,C'$$

Then $$f(x) = (B + C)(A + B' + C')(X + A' + B'\,C') \quad (18\text{-}17)$$

$$= (B + C)(A + B' + C')(X + A') \quad (18\text{-}18)$$

If h(x) is determined by the second or release combinations method, (intervals 5 and 9), then:

$$\begin{aligned} h(x) &= [(A + B + C')(A + B' + C)]' \\ &= A'B'C + A'BC' \\ &= A'(B'C + BC') \\ &= A'(B' + C')(B + C) \end{aligned} \quad (18\text{-}19)$$

And

$$\begin{aligned} f(x) &= (A + B' + C')(B + C)[X + A'(B' + C')(B + C)] \\ &= (A + B' + C')(B + C)[X + A'(B' + C')] \\ &= (B + C)(A + B' + C')(X + A') \end{aligned} \quad (18\text{-}20)$$

The results of the two methods are identical.

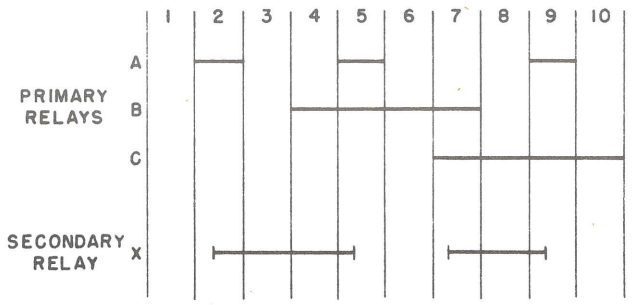


Figure 18-8 Sequence With Two Operations of a Secondary Relay

Actually the third, or inspection method, will give the hold path here in the shortest time because it is apparent that the operation of (A) is responsible for both releases, and A' will therefore serve as a holding contact in all hold intervals. However, on comparing equation 18-20 with the sequence of Figure 18-8, it will be observed that unless a continuity transfer is used, a temporary break in the energization of relay (X) may occur between intervals 2 and 3 when the relay energization path transfers from (A + B' + C') to (A' + X) on the release of relay (A). This situation arises frequently with control paths of secondary relays. Either a continuity transfer must be used or the contacts manipulated by applying theorem (12) of Chapter 15 which states that

$$(X + Y)(X' + Z) = XZ + X'Y \quad (18\text{-}21)$$

Using this theorem in this example, the control path becomes,

$$f(X) = [AX + A'(B' + C')](B + C) \quad (18\text{-}22)$$

In this form no discontinuity occurs in the control path of relay (X). Figure 18-9 shows the control of relay (X) corresponding to equation 18-20 and with a continuity transfer on relay (A). Figure 18-10 shows control of relay (X) corresponding to equation 18-22, with a break-make transfer on relay (A).

Circuits considered so far have contained only one secondary relay. Design approach is not materially altered when several secondary relays are involved. The control of each relay is considered separately, assuming that other secondary relays operate in the desired sequence although their control paths may not yet have been designed. With all paths independently completed, the circuit will act in the sequence indicated.

For example, take the sequence of Figure 18-11. Since (C + Y') is a unique combination in interval 4:

$$g(x) = C + Y' \tag{18-23}$$

By inspection, a break contact to ground on relay C will be sufficient for holding (X) so:

$$h(x) = C' \tag{18-24}$$

Substituting in the general equation $f(x) = g(x)\,[x + h(x)]$:

$$f(x) = (C + Y')(X + C')$$

Rearranging to avoid a continuity transfer on (C)

$$f(x) = CX + C'Y' \tag{18-25}$$

Similarly for control of relay (Y), (B' + X) is a unique combination in interval 6 so:

$$g(y) = B' + X \tag{18-26}$$

By inspection (Y) can lock to a make contact on relay (A):

$$h(y) = A \tag{18-27}$$

Substituting in the general equation:

$$f(y) = (B' + X)(A + Y) \tag{18-28}$$

The complete secondary control circuit is shown in Figure 18-12.

Much of the combination and simplification of the previous examples could have been done by the tabular method of Chapter 15. If the number of relays is not too large, the tabular method of denoting sequence gives a direct approach to the subsequent contact manipulation. Operate, hold, and release combinations can be selected from the table by observing where the secondary relay to be controlled changes state. The tabular method

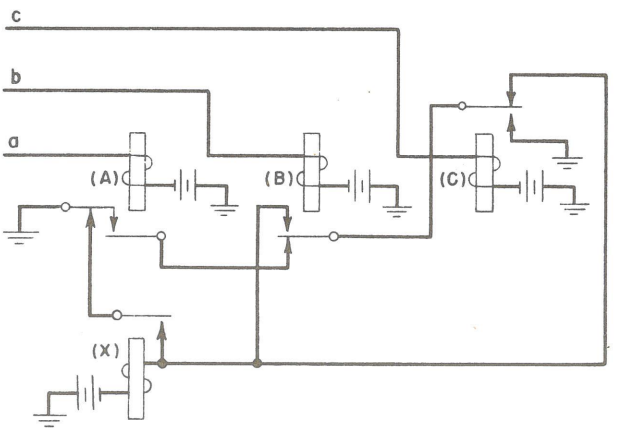


Figure 18-9 Control Circuit for Relay (X) of Figure 18-8

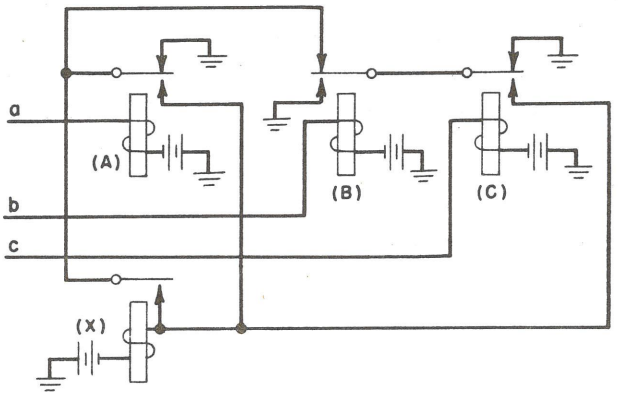


Figure 18-10 Rearranged to Eliminate Continuity Transfer

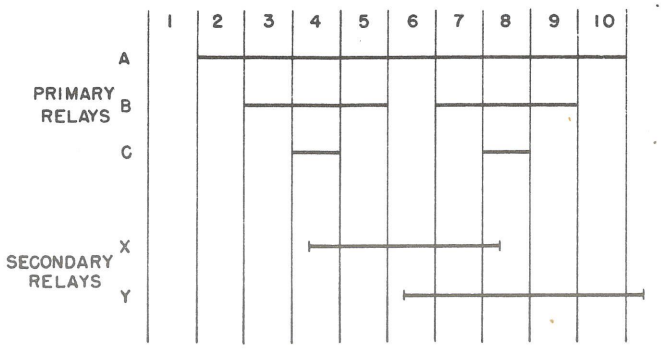


Figure 18-11 Sequence With Two Secondary Relays

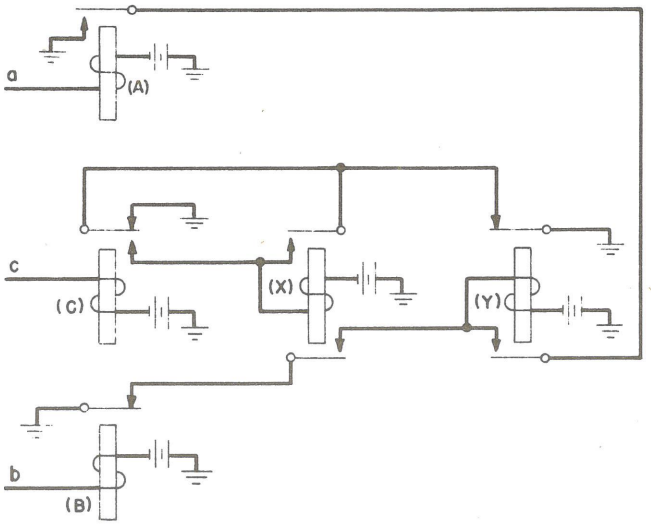


Figure 18-12 Control Circuit for Relays (X) and (Y) of Figure 18-11

will be used for a final secondary relay control example in which all of the relays incidentally are internally controlled. Such a circuit will run through its sequence cycle continuously as long as power is provided. This particular sequence, shown in Figure 18-13, uses all combinations of four relays.

	A	B	C	D
1.	1	1	1	1
2.	0	1	1	1
3.	0	0	1	1
4.	0	0	0	1
5.	1	0	0	1
6.	1	1	0	1
7.	0	1	0	1
8.	0	1	0	0
9.	0	1	1	0
10.	0	0	1	0
11.	0	0	0	0
12.	1	0	0	0
13.	1	1	0	0
14.	1	1	1	0
15.	1	0	1	0
16.	1	0	1	1

Figure 18-13 Table of Sequential Requirements

One relay (D) operates and releases once in the cycle. It is energized in interval 7 by combination (A + B' + C) and released in interval 15 by combination (A' + B + C').

$$\begin{aligned} f(d) &= (A + B' + C)[D + (A' + B + C')'] \\ &= (A + B' + C)(D + AB'C) \end{aligned} \qquad (18\text{-}29)$$

From intervals 1 and 6 for g(a), 4 and 11 for h(a)

$$\begin{aligned} f(a) &= (B' + C' + D')(B' + C + D')(A + B'C'D + B'C'D') \\ &= (B' + D')(A + B'C') \end{aligned} \qquad (18\text{-}30)$$

From intervals 2, 9, and 14 for g(b); 5, 12, and 16 for h(b)

$$\begin{aligned} f(b) &= (A + C' + D')(A + C' + D)(A' + C' + D)(B + AC'D + AC'D' + ACD) \\ &= (C' + AD)[B + A(C' + D)] \\ &= C'B + AC' + AD \\ &= C'(A + B) + AD = (C' + AD)(A + B) \end{aligned} \qquad (18\text{-}31)$$

(Notice that in its third operation relay (B) requires no holding path since it is to release as soon as its operate path is opened.)

From intervals 3 and 10 for g(c); 8 and 13 for h(c):

$$f(c) = (A + B + D')(A + B + D)(C + A'BD' + ABD') \qquad (18\text{-}32)$$
$$= (A + B)(C + BD')$$

The combined circuit for all four relay paths is shown in Figure 18-14. Hazards exist in this circuit due to possible stagger of contact closures on a given relay. Thus, if relay (B), which operates in Figure 18-14 through (A + C') in interval 2, were to operate relay (C) in interval 4 before it closed its locking path (A + B), it would drop an interval sooner than planned and the circuit would jump interval 5. Such hazards exist for the other relays also and may be eliminated by "preliminary makes" in the locking paths or by making sure that contact stagger time is less than the acting time of the controlled relay.

18.5 EFFECT OF RACE CONDITIONS ON INTERNAL CONTROL

It is sometimes convenient in a sequential circuit to have one relay by its operation affect directly several relays at the same time. A sequence diagram showing several such actions is shown in Figure 18-15. In interval 3 both (X) and (Y) are to operate immediately when (K) releases, but there will always be slight difference between the times that (X) and (Y) reach the operated position. Thus either combination (K' + W + X + Y' + Z') or (K' + W + X' + Y + Z') will exist for a short time in interval 3. As a result, these two combinations must produce no result should they occur momentarily, or they may disrupt the sequence of the cycle. If a prescribed order were set forth for the operation of relays (X) and (Y), one of these two combinations would be specified and the other could then not occur. Thus (Y) could be operated through a make contact on (X) and combination

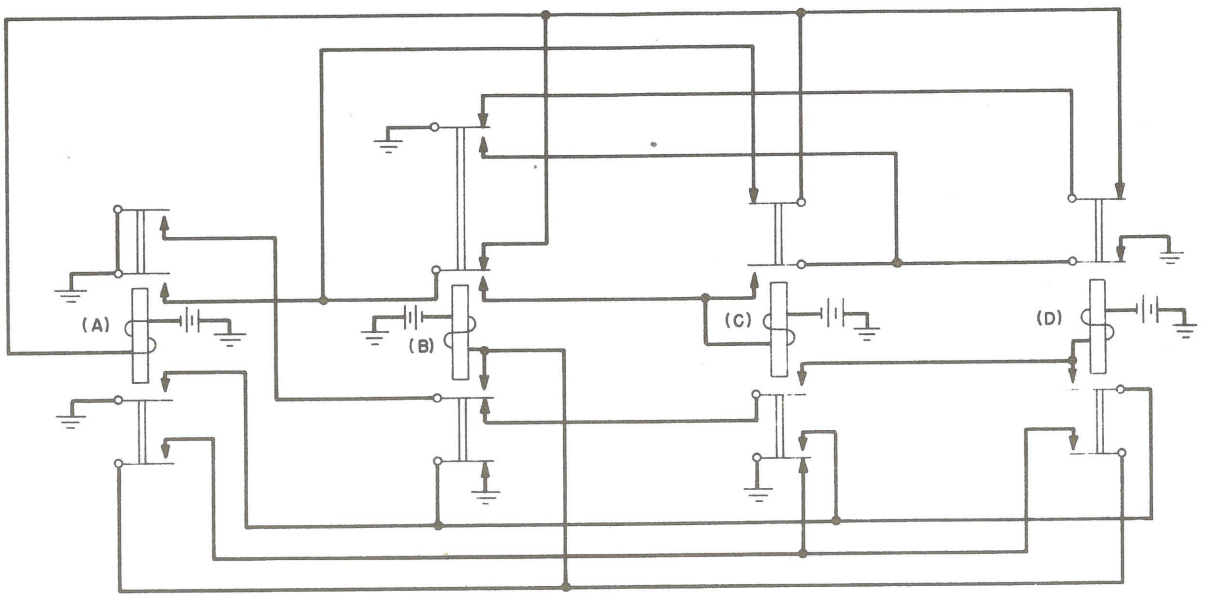


Figure 18-14 Recycling Circuit on Four Relays

(K' + W + X' + Y + Z') would become available as an unused combination. The same sequence could be achieved by making relay (Y) slower in operating then relay (X).

In interval 5 there is a race of (X) releasing and (Z) operating, again resulting in two combinations that cannot be used. Similarly for intervals 7 and 9.

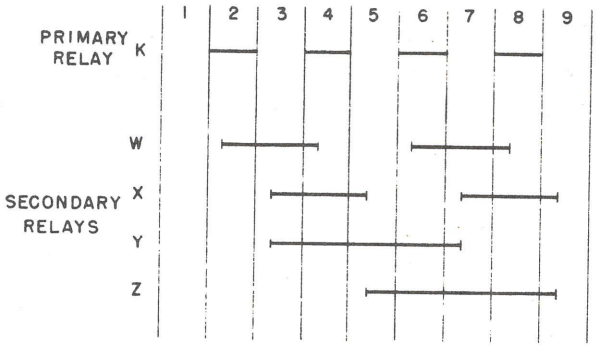


Figure 18-15 Sequence With "Simultaneous" Secondary Relay Actions

In addition to limiting the number of combinations usable for simplification, race conditions necessitate careful analysis to prevent false output conditions as was discussed in Chapter 16. The reason for putting in such conditions is generally to increase the speed of the over-all circuit performance when relays do not all have to act in sequence.

18.6 PROVIDING OUTPUT CONDITIONS IN SEQUENTIAL CIRCUITS

The output conditions which a sequential circuit establishes may last for one interval only, or extend over several intervals, or appear several times. In each interval the problem of establishing the proper output conditions if of the combinational type. The only difference is that when an output condition extends over several intervals, care must be taken that the condition is maintained continuously. This problem is the same as that of maintaining continuous hold paths and may require contact manipulation or use of continuity transfers.

18.7 PRELIMINARY SEQUENCE DIAGRAMS OF REQUIREMENTS

When developing a scheme of actions for a sequential circuit, a preliminary sequence diagram showing inputs and outputs will facilitate the selection of a good plan of operation for the secondary relays. These diagrams may be more or less complete, with the omitted requirements covered by supplementary notes. The sequence of operation is generally shown indicating operations from a convenient starting point, which is the normal state, and is continued until the normal state is reached again. Such a sequence, from the normal state back to normal, is a circuit cycle. The combination usually selected as normal is that of all relays released or of no inputs present, but with some circuits other combinations may be used. Variations exist in the types of sequences encountered in sequential relay circuits and a knowledge of some of the basic types will be found helpful.

The most direct type of sequential circuit moves through a single cycle in response to input combinations that always occur in the same sequence. The illustration used in the opening paragraphs of this chapter was of this nature as it was assumed that the actions always took place in the same order. The transfer of stated requirements to the sequence diagram was achieved directly since the sequence of actions was clearly defined.

In other cases, requirements may state that a circuit is to pass through several different cycles depending upon the sequence in which input conditions are applied. In making a diagram of these requirements, it is usually convenient to put all of the alternative cycles in an arbitrary order on the diagram with a normal interval preceding each one. Thus, although the diagram appears to state a definite order in which alternate events occur, the completed circuit will follow any one of the alternative cycles from the normal state whenever the input conditions are applied in the appropriate sequence. The normal intervals must all be kept alike in both primary and secondary relay combinations, so that no cycle is affected by the previous cycle through which the circuit has passed.

To illustrate an alternative cycle, the requirements of the first example are extended as follows:

At each end of a tie trunk between switchboard positions A and B, two lamps are provided, designated (ANS) for answer and (DIS) for disconnect. The operator who plugs into the tie trunk first is to cause the (ANS) lamp at the other position to be lighted. It is to be extinguished when the other operator plugs into the trunk in response. The operator who first removes her plug after this is to cause the (DIS) lamp at the other position to be lighted. This in turn is to be extinguished when the plug at that end is removed.

Four alternative sequences of input appearances are included in these requirements which are shown in Figure 18-16. In each case the output depends upon the input sequence. Intervals 1, 5, 9, 13, and 17 are all normal with no input leads grounded.

In analyzing the requirements of a sequential circuit, consideration must be given to all conceivable sequences. Of these a large number may usually be discarded as being known never to occur. In many cases, however, the statement of requirements may not mention some of the possible cycles. For example, in the

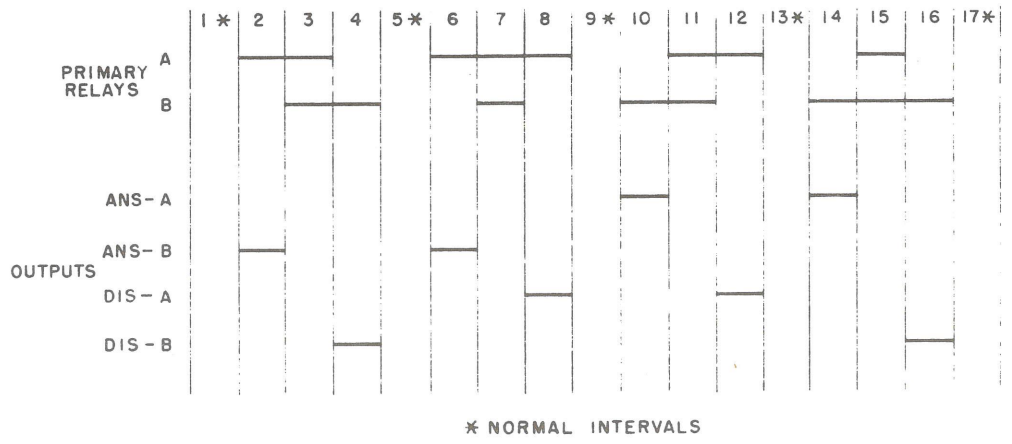


Figure 18-16 Sequence With Alternative Cycles

previous statement, no mention was made of what action the circuit was to take if an operator should remove her plug without waiting for an answer. In practice, a designer would probably have to verify that this sequence never occurred, or if it did occur, ascertain what action should be taken.

The number of alternative cycles may easily rise too high to allow the complete representation of each cycle on a practical sequence diagram. For example, all of the circuits involved in setting up a call from one subscriber to another must be capable at many or all stages of their operation to return to normal should the call be abandoned by the originating subscriber. This sort of general requirement involving a large number of alternative cycles is easily understood and is most usable in its simple verbal form rather than in a long series of repetitious sequence diagrams.

Similarly, it is sometimes desirable to have a circuit continue upon its cycle regardless of whether a particular input condition is present or not. Again, an alternative cycle for each possible sequence in which this input can occur without affecting circuit operation is unduly repetitious. Instead, a verbal statement may be made to the effect that a certain input may occur out of the sequence shown and is not to affect the circuit operation at such times. Another method is to state as an output requirement that the lead over which this certain input is applied is to be opened during the appropriate intervals.

A third type of requirement calls for the establishment or change of an output combination with no corresponding change of input combination. In making a sequence diagram of this type of requirement, it is convenient to let the appearance of such an output combination start a new interval. For example, let us consider the tone circuit associated with the terminating end of a manual straightforward trunk. In response to an input of a single grounded lead, this circuit is to apply two spurts of tone to the tip and ring conductors of the trunk as a signal to the originating operator that an operator at the terminating end of the trunk is ready to handle the call. The two tone spurts and the space between must obviously be timed internally by the circuit. The sequence diagram of inputs and outputs is shown in Figure 18-17 where intervals 3, 4, and 5 are internally generated.

18.8 PLANNING THE SEQUENTIAL CIRCUIT

After the requirements of a sequential circuit have been determined, the next step in design is to plan the sequence in which secondary relays shall operate. The preliminary diagram of the sequence of primary relay operations and of the output appearances serves as a convenient framework to which the sequence of secondary relay operations can be added.

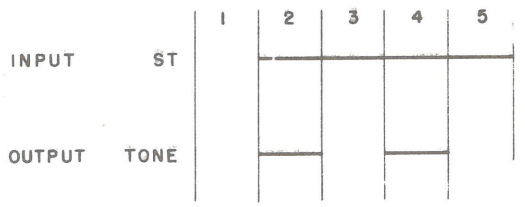


Figure 18-17 Sequence Requiring Internally Generated Intervals

First, those intervals must be determined which have to be identified by secondary relay combinations. Evidently if no primary relay combinations occur twice and no output combination is to change without a change in input, no secondary relays are needed at all. The requirements in such a case are those of a combinational circuit and sequence is unimportant unless continuity of an output condition is to be maintained from interval to interval.

The most evident need for secondary relay combinations occurs when in the preliminary sequence diagram there are intervals having identical inputs but different outputs. Thus in the requirements of Figure 18-2, intervals 2 and 4 had similar inputs, hence a different relay combination is needed in interval 4 to provide a new output combination. If an input combination appears several times and is to establish a different output each time, more secondary relay combinations have to be used.

The relay combination used to identify an interval in which an input is repeated may be used also to identify another interval in which a different input is repeated. For example, in the preliminary sequence diagram of Figure 18-16 a single secondary relay may serve to meet the requirements. As shown on Figure 18-18 in conjunction with relay (B) it differentiates intervals 4 and 16 from 10 and 14, and in conjunction with relay (A) it differentiates intervals 8 and 12 from 2 and 6.

Two identical input intervals may have to be identified separately not for the purpose of producing different outputs in those intervals, but to steer future circuit actions. Suppose, for example, a circuit is to be provided which will respond to a number of pulses such as dial pulses applied to a single lead. At the end of a train of consecutive pulses, a second input lead is grounded, and the circuit is to ground an output lead corresponding to the number of pulses received.

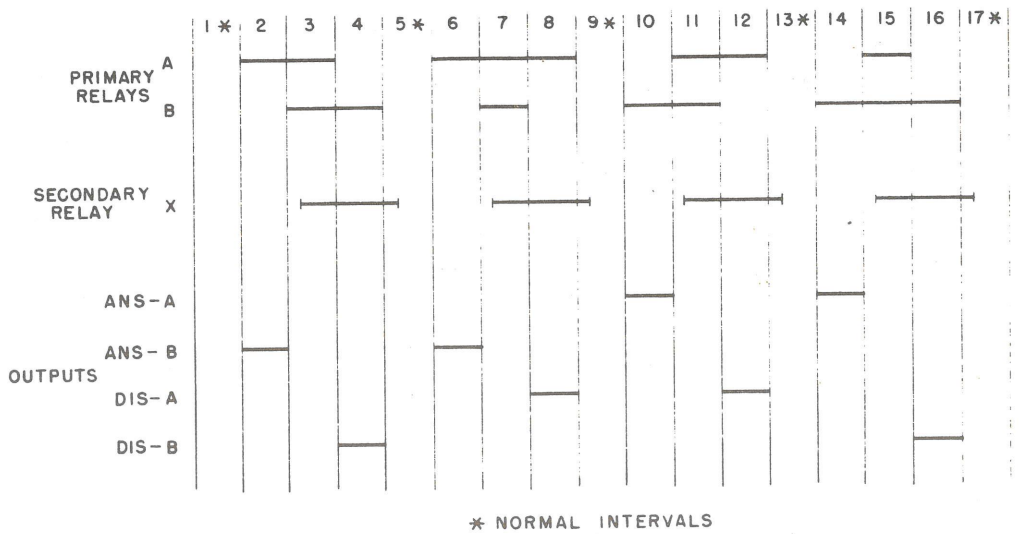


Figure 18-18 Sequence of Figure 18-16 With Single Secondary Relay

Such a sequence, calling for outputs on leads "1" or "2" corresponding to one or two pulses is shown in Figure 18-19. This sequence contains two alternative cycles and although no output is established by the second appearance of input combination (A + B') in the second cycle, it is evident that this second appearance must produce a different secondary relay combination from that produced by the first appearance in order that the circuit may establish a different output when relay (B) operates. Figure 18-20 shows one sequence of secondary relay action which meets these requirements.

With a full understanding of which intervals must be differentiated, the necessary secondary relay combinations and the sequence of secondary relay actions must then be decided upon. In this planning, the following points should be kept in mind:

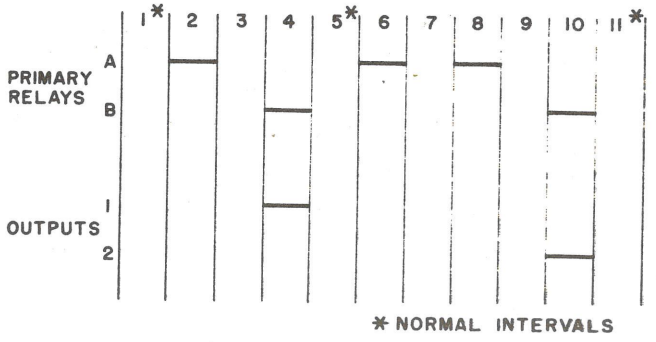


Figure 18-19 Sequence Requiring Secondary Relays to Direct Subsequent Action

1. The intervals in which each secondary relay operates and releases must contain relay combinations suitable for operating and releasing the secondary relay. As will be seen it may be necessary to add secondary relays for this purpose alone in some other intervals.

2. Simultaneous energization of relays may introduce race conditions or make certain relay combinations unavailable for use in other intervals.

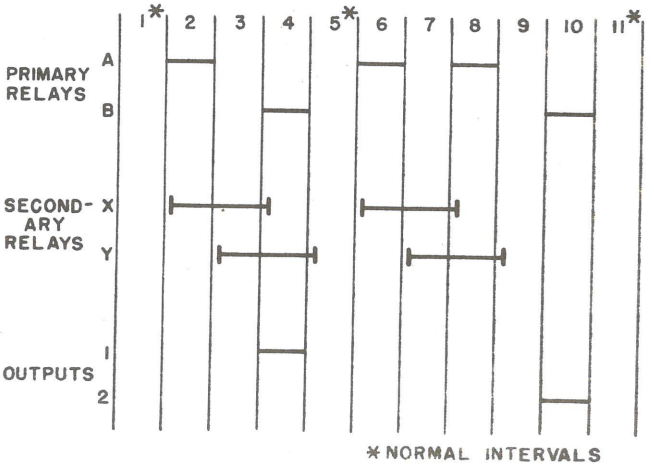


Figure 18-20 Sequence of Figure 18-19 With Two Secondary Relays

3. As the number of secondary relays operating in a fully developed cycle is increased, the control of each secondary relay becomes complex. When five or more secondary relays are used in such cases, most of the contacts that can be carried by general purpose relays will be needed for internal control, leaving no contacts for output control. In these circuits the use of more than the minimum number of required secondary relays will generally simplify internal control and output contact networks.

4. A relay cannot identify by itself the interval in which it operates since it appears in that interval in both the operated and non-operated positions.

In addition to these basic principles, there are some further facts which help to eliminate the choice of some of the sequences that result in more complicated circuits:

(a) If an operation of a secondary relay can be made to coincide with the appearance of an output condition, the output paths often may be greatly simplified.

(b) If the secondary relay is operated more than once in a cycle, using different operate and release paths, the control paths will usually be more complicated.

It can be seen from these principles of sequential circuit planning that no hard and fast rules apply which deliver, consistently, the best circuit to the designer on his first attempt. Ingenuity plays a significant part in relay circuit design; the possibility that some different sequence or different contact arrangement gives a better circuit is always present.

Let us consider some of the problems encountered in selecting secondary relay sequences by looking at several theoretical input sequences. Figure 18-21 shows a cycle with two input combinations repeated, (A + B' + C') in intervals 2 and 8, and (A + B + C') in intervals 3 and 7. An output is to be established only in intervals 7 and 8. One secondary relay operated through intervals 7 and 8 will serve to differentiate between the similar input combinations. Many combinations are available as operate or release combinations for this secondary relay; the secondary relay may be operated in intervals 4, 5, or 6 and released in intervals 9, 10, or 11 (normal). The governing factor in picking the secondary relay control intervals will be the simplicity of the control path, since the secondary relay cannot be made to operate only in the intervals in which the output appears. By inspection, if a single make contact on relay (C) is chosen to operate the secondary relay, it will operate the relay in intervals 5 and 6, 9 and 10. To hold it during intervals 7 and 8 requires only a locking contact to a make contact on relay (A). The following simple control path is thus obtained:

$$f(x) = C(A + X) \qquad (18\text{-}33)$$

where (X) is the secondary relay designation.

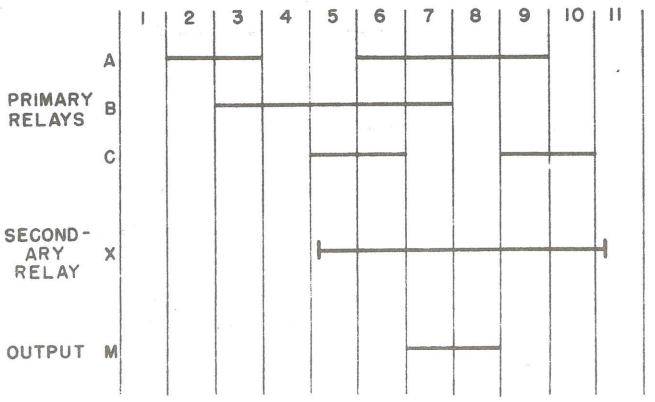


Figure 18-21 Sequence With Several Combinations Available for Control

The sequence of Figure 18-22 does not allow as much freedom of choice of secondary relay control intervals. Here, interval 12 must be differentiated from interval 6 in order to produce a new relay combination to establish the output

condition in interval 12. A secondary relay is therefore needed. Let us first try having the relay operated during interval 6 and released during 12. Difficulties are immediately encountered in choosing the interval in which the relay is to release because the primary relay combination in interval 2 is the same as in the interval 8, the one in 3 the same as in 9, and so forth. It is evident that if the secondary relay is operated in intervals 2, 3, 4, or 5 and held through 6 it will also operate in one of intervals 8 through 11 and hold through 12, with the result that the intervals to be differentiated still contain the identical relay combination. Similarly the relay cannot be operated during interval 12 and released during interval 6 by bringing it to the operated position in any of intervals 8, 9, 10, or 11. This leaves only the combinations of interval 1 (same as 13) and of interval 7 available as control combinations. Assuming that it is undesirable to have the secondary relay operated throughout the normal interval, it must be operated in interval 7 and released in interval 13 as shown in Figure 18-23.

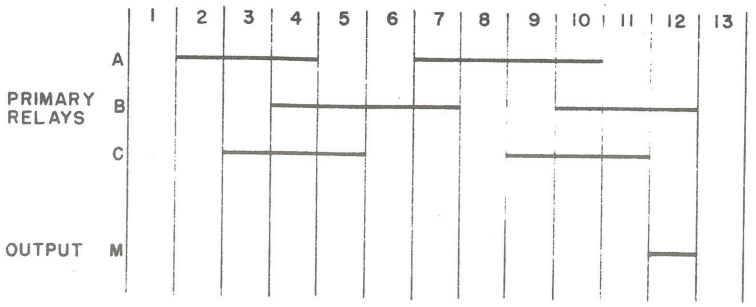


Figure 18-22 Sequence With Two Combinations Available for Control

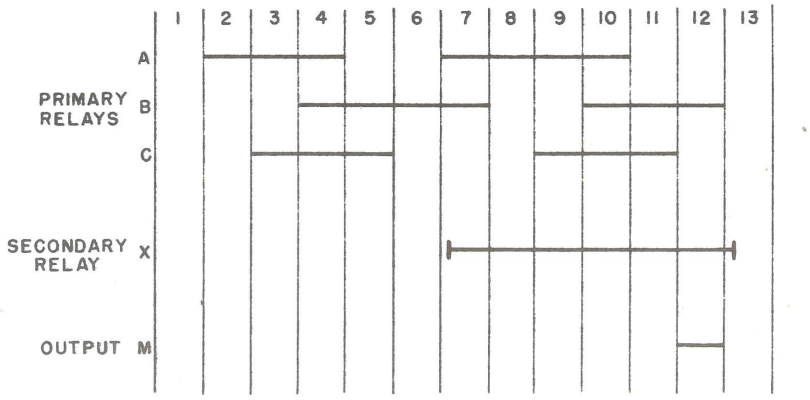


Figure 18-23 Sequence of Figure 18-22 With Single Secondary Relay

The sequence of Figure 18-24 will offer considerable difficulty in the search for intervals containing suitable operate combinations. In order to provide an output in interval 13 but not in interval 7 where the primary relay combination is the same, let us attempt to have the relay in the operated position during interval 7. It is evident, on studying the situation, that the sequence of relay combinations is the same from interval 2 to 7 as it is from interval 8 to 13. As a result, interval 1 contains the only combination which can be used to operate relay X so that it will be in the operated state during interval 7 without also having it operated during interval 13. Even if the relay could be allowed to operate in the normal interval 1, however, there is no primary relay combination which will release the secondary relay between intervals 7 and 13 because that same combination occurring before interval 7 will release the relay prematurely. The same difficulties arise in trying to find methods of controlling the relay to be in the operated state in interval 13 and in the released state in 7. True, the combinations in intervals 14 or 15 (normal) could be used as release combinations, but no

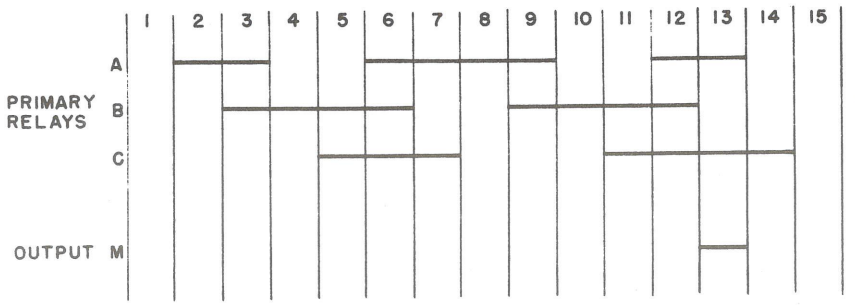


Figure 18-24 Sequence Requiring Two Secondary Relays

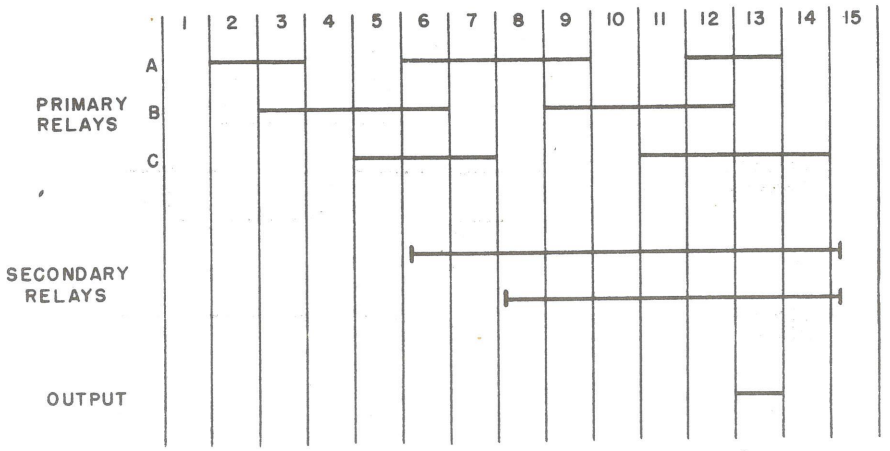


Figure 18-25 One Sequence of Secondary Relay Operation for Requirements of Figure 18-24

suitable operate condition can be found. It is necessary, therefore, to add an additional secondary relay which will make one of the intervals between 7 and 13 dissimilar from the corresponding one preceding interval 7. Once this is realized, there is a wide choice of intervals in which to operate and release the two secondary relays. One such choice is shown in Figure 18-25. This problem of needing an additional relay for the sole purpose of providing control combinations for another secondary relay arises whenever the sequence between two similar intervals which are to be differentiated is the same as the sequence preceding the first of the two.

The requirements of Figure 18-17 present a different problem in sequence planning. Here, the secondary relay acting times must generate intervals 3, 4, and 5. No secondary relay combination may be repeated because then the circuit would continue recycling itself as long as the start lead was grounded. A minimum of two relays is needed in this example. These have four possible combinations and every one must be used since different combinations must be established in each of intervals 2, 3, 4, and 5. A sequence with two secondary relays is shown in Figure 18-26 with a primary relay controlled by the start lead. Some practical difficulty might be experienced, however, in selecting relays which are slow enough in operating to give sufficient duration to the intervals. A sequence such as that of Figure 18-27 might prove more desirable, where interval 2 is formed by three relay operating times added together, and intervals 3 and 4 are both generated by relays releasing.

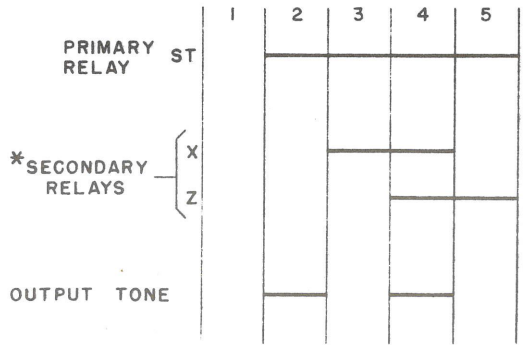


Figure 18-26 One Sequence of Secondary Relay Operation for Requirements of Figure 18-17

18.9 DESIGN OF A PRACTICAL SEQUENTIAL CIRCUIT

During the development of a complex relay circuit, it is almost impossible to consider completely the effects of every temporary path closure that may possibly occur while relays are in the process of operating or releasing. However, an analysis of these temporary closures must be made at the conclusion of design to determine whether or not they will be hazardous to proper circuit operation. To demonstrate the nature of such hazards, the procedure of designing

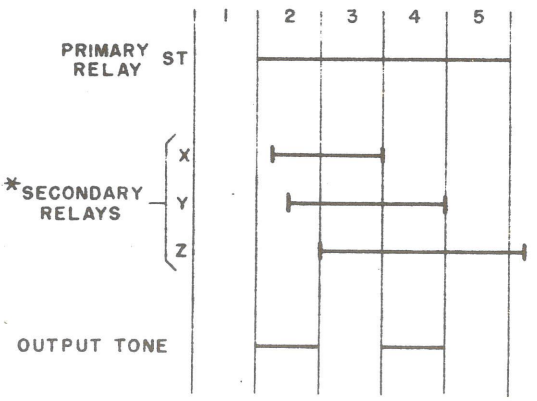


Figure 18-27 Another Sequence of Secondary Relay Operation for Requirements of Figure 18-17

a small sequential circuit will be outlined next and its performance analyzed. Then one of the circuits meeting the same requirements, which is in use in many locations, will be analyzed for comparison.

The problem of differentiating between successive pulses arises frequently in telephone switching. For example, in the detection of dial pulses it may be desirable to provide a circuit to determine whether an odd or even number of pulses have occurred. One of the early types of circuits meeting this sort of requirement consisted of two relays which were designated W and Z. For this reason such a circuit regardless of the number of relays is often referred to as a "W-Z Combination." A circuit with sequence requirements as shown in Figure 18-28 will provide such indications, grounding a lead "O" on and after the odd pulses and a lead "E" on and after the even pulses. (No pulses at all is considered an even pulse.) This cycle requires at least two secondary relays because, while one relay operating as shown in Figure 18-29 will provide the proper output, no control combinations are available, since the relay is to be operated and released by the same input combination. Another secondary relay must therefore be added. Assuming that it is desirable to have all relays released in interval 1, the three sequence diagrams of

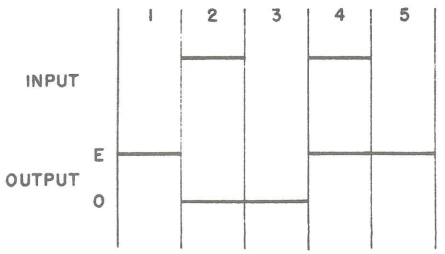


Figure 18-28 Requirements of a W-Z Combination

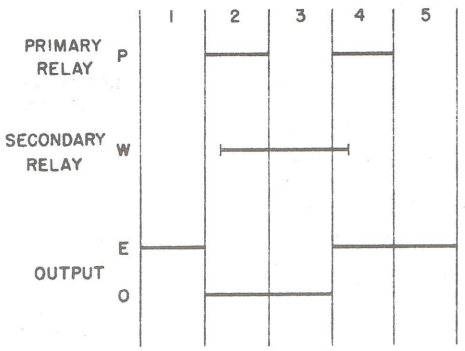


Figure 18-29 Action of Secondary Relay to Provide Outputs of Figure 18-28

Figure 18-30 represent all of the sequences of actions of two secondary relays which can provide the proper output. Both the sequence of Figure 18-30B and C include prohibitive race conditions; however, if, for example, in Figure 18-30B, in interval 2, one relay operates slightly before the other, then one of the two relay combinations of interval 4 obtains and the action would immediately jump to that interval. Since it is impractical to design relays which will always operate simultaneously when they are energized simultaneously, sequences involving races of this kind cannot be considered.

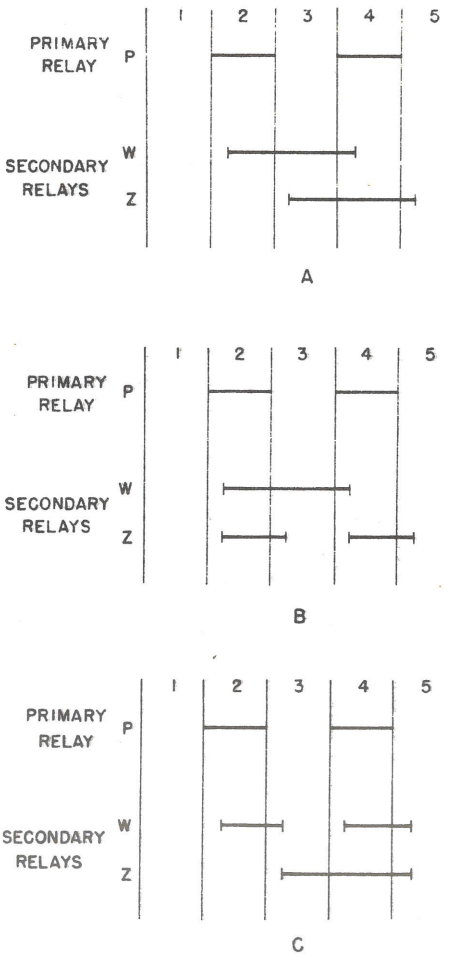


Figure 18-30 Secondary Relay Sequences for W-Z Combination

We shall therefore adopt the sequence of Figure 18-30A which is apparently the only practical sequence of action for two secondary relays to meet the requirements. The following control paths are easily obtained:

$$g(w) = P + Z' \qquad (18\text{-}34)$$

$$h(w) = P'Z' \qquad (18\text{-}35)$$

$$f(w) = (P + Z')(W + P'Z')$$
$$= PW + Z'W + P'Z' \qquad (18\text{-}36)$$
$$= PW + P'Z'$$

$$g(z) = P' + W \qquad (18\text{-}37)$$

$$h(z) = PW \qquad (18\text{-}38)$$

$$f(z) = (P' + W)(Z + PW)$$
$$= P'Z + WZ + PW \qquad (18\text{-}39)$$
$$= PW + P'Z$$

The term PW may be made common to both equations and will appear as in Figure 18-31A. This can be further simplified by making P' a bridging path between Z and W by modifying f(w) to PW + (P' + Z)Z' and f(z) to PW + (P' + Z')Z as shown in Figure 18-31B. In this form, when relay (Z) operates, the path of relay (W) is shifted from (PW + Z') to (PW + P' + Z) so a continuity transfer is required on Z. Similarly the shift from the operate to the hold path of relay (Z) on its operation requires the continuity transfer. This configuration is shown in Figure 18-32.

The hazards of this circuit are as follows:

1. When relay (P) first operates, if contact P makes before P' breaks, ground is applied to the windings of both (Z) and (W). Both (Z) and (W) will start

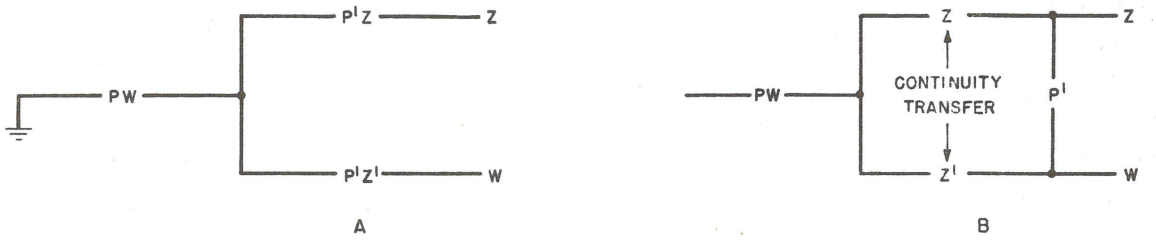


Figure 18-31 Combining Contacts in Equations 18-38 and 18-39

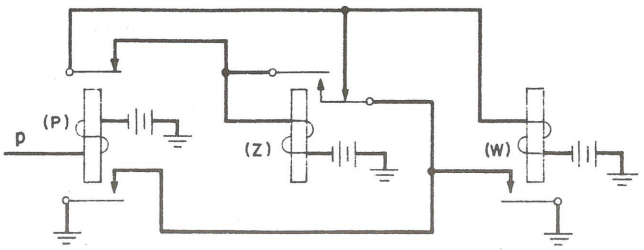


Figure 18-32 W-Z Combination With Hazards

to operate, and if contact Z makes, relay (Z) will continue to operate. Relay (W) will then fall off when P' breaks.

2. Assuming the circuit to have operated correctly when the second pulse was applied, on the removal of the pulse if P' makes before P breaks, (W) is energized through Z + P', and if (W) operates, it will lock through W + Z + P', hold (Z), and leave the secondary relays in the combination meant to follow the first pulse.

3. When P operates the second time, with relays (W) and (Z) both operated, if P' breaks before P makes (opposite of hazards 1 and 2) and (W) is fast in releasing, contact (W) may open before contact P closes, (Z) will drop and (W) will reoperate and lock in, leaving the secondary relays in the combination for the first pulse.

Let us now analyze the circuit with which the name W-Z combination originated. This circuit was designed to eliminate the primary relay altogether, and since in interval 3 the removal of a ground operates a relay, and in interval 4 the application of ground releases a relay, lock-down and shunt-down control paths had to be used. The use of the shunt-down reduces the speed at which the circuit responds to its inputs.

Figure 18-33 shows the configuration of the W-Z combination which operates as follows:

Relay (W) (see Figure 18-34) operates through its own back contact on the first pulse and locks to ground. This spring combination must be a continuity transfer since the circuit would buzz if the operating ground were discontinued before the locking ground were closed through. (W) remains operated until the second pulse shunts it down through contact Z. In releasing, (W) removes its

locking ground. Removal of the pulse removes both shunt and operate ground so (W) stays released.

Relay (Z) (see Figure 18-35) is locked down when the first pulse is applied with the pulse supplying the shunting ground. An operating ground is furnished by the locking ground of relay (W) so that when the shunting pulse is removed, (Z) operates. On the second pulse when (W) releases, the pulse furnishes a holding ground for (Z) which is then released when the pulse is removed.

These paths may be expressed algebraically as follows, where f_d represents direct control paths and f_s represents shunt control paths.

$$f_d(W) = (W)(W' + P) \qquad (18\text{-}40)$$

$$f_s(W) = Z + P \qquad (18\text{-}41)$$

$$f_d(Z) = (W' + P)(W) \qquad (18\text{-}42)$$

$$f_s(Z) = P + Z' \qquad (18\text{-}43)$$

Plotting these functions on a sequence diagram, with a solid line denoting closure of a path, gives Figure 18-36. The equation presented in Chapter 15, $f(x) = f_d(x) + [f_s(x)]'$ can be used to derive these functions from equations 18-36 and 18-39.

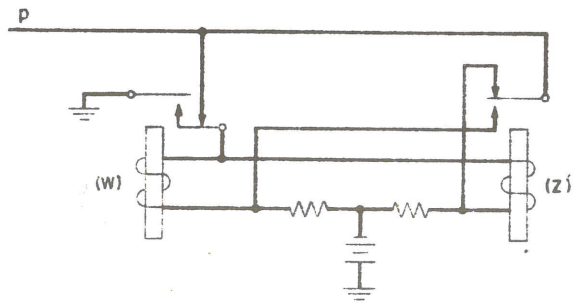


Figure 18-33 Two-Relay W-Z Combination

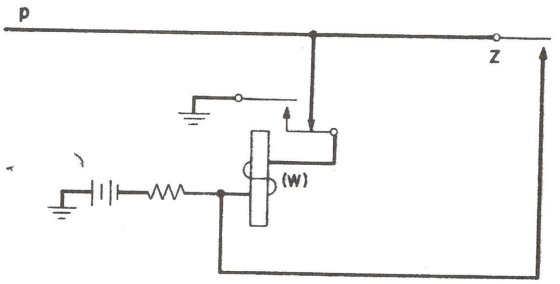


Figure 18-34 Control of Relay (W)

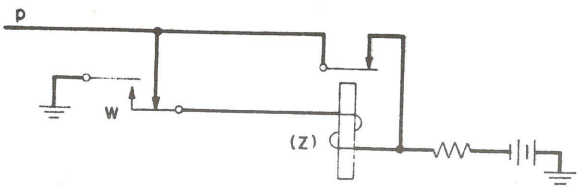


Figure 18-35 Control of Relay (Z)

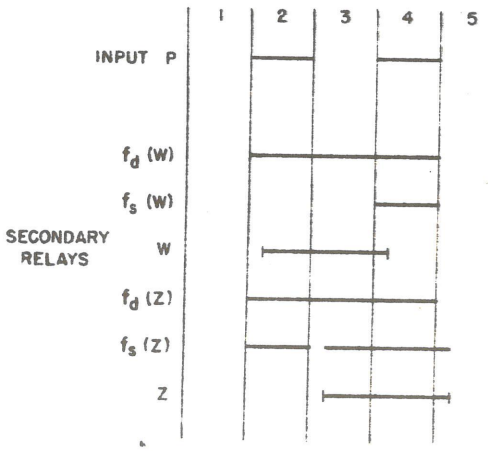


Figure 18-36 Sequence of W-Z Combination Control Path Closure

CHAPTER 19

DESIGN OF POSITIONAL RELAY CIRCUITS

19.1 GENERAL

A positional relay circuit does not use specific input combinations and sequences as the sole basis upon which output combinations are established, but also takes into account in its pattern of operation the relative position of the inputs with respect to each other. In the design of combinational relay circuits, developed in Chapter 16, it was necessary to consider all input combinations that could occur, and to operate relays in corresponding combinations to provide the desired output combinations. In sequential relay circuits, developed in Chapter 18, the effect of every expected input sequence upon relay control paths had to be taken into account as well. In positional circuits, the conditions under which a relay is to operate are influenced by its position relative to the position of other relays already operated at that time.

Positional circuits are generally designed to meet requirements that include such a large number of possible input combinations and input sequences that the technique of considering them individually is impractical. In the resultant circuit, the contact network connections of one relay to, say, the relay on its left will be the same as the contact network connections of any other relay to the one on its left, while the control paths of all such relays will be similar. This consecutive and identical connecting of relays results in a chain and is characteristic of positional circuits.

An example will serve to show the general nature of requirements that are met by positional circuits. Suppose that twenty input leads are to be grounded in random sequence. Each input lead when grounded, is to ground a corresponding output lead. A circuit is to be designed which, at any specified time, will allow only one of the input leads to ground its corresponding output lead. The particular input lead for which the output is established will be said to have been "served." It is desired that the circuit tend to serve input leads which have been grounded for the longest times, although it is not necessary to serve them in the exact sequence in which they were grounded. Since all combinations and sequences of input appearance are possible here, consideration of each of the 2^{20} (= 1,056,784) combinations and of the much larger number of sequences is obviously out of the question. The requirements leave wide latitude as to the basis upon which any particular input lead is served, and, as a result, a general pattern

of operation can be determined in which relay operations depend to some extent upon relay position with respect to other operated relays.

19.2 THE BASIC POSITIONAL RELAY CONFIGURATION

Let us first determine a convenient pattern for serving one of a large number of inputs on the basis of the input combination present. Such a choice must usually be made even where service is to depend mainly on input sequence, in order to take care of simultaneous input appearances. As in preceding chapters, the inputs will be assumed to be grounded leads controlling individual relays. The simplest and most logical pattern to adopt here consists of giving service to the lowest (or highest) numbered lead grounded, with all input leads numbered consecutively. Consider, for example, four input leads, a_1, a_2, a_3, and a_4, controlling relays designated (P_1), (P_2), (P_3), and (P_4) which are to establish outputs on leads b_1, b_2, b_3, and b_4, respectively, subject to the above stated pattern. Using the tabular form, the output established for each combination is shown in Figure 19-1.

	P_1	P_2	P_3	P_4	Output Lead Grounded
1.	1	1	1	1	None
2.	0	1	1	1	b_1
3.	0	1	1	0	b_1
4.	0	1	0	0	b_1
5.	0	1	0	1	b_1
6.	0	0	0	1	b_1
7.	0	0	1	1	b_1
8.	0	0	1	0	b_1
9.	0	0	0	0	b_1
10.	1	0	1	1	b_2
11.	1	0	1	0	b_2
12.	1	0	0	1	b_2
13.	1	0	0	0	b_2
14.	1	1	0	1	b_3
15.	1	1	0	0	b_3
16.	1	1	1	0	b_4

Figure 19-1 Table of Possible Input Combinations With Output Corresponding To Lowest Numbered Input Condition

The combined circuit is shown schematically in Figure 19-2, and is seen to be simple and convenient to use. The contact configuration will be recognized as the break connected transfer chain introduced in Chapter 14. This type of transfer chain forms the base of almost every positional circuit. Once its properties are recognized, it need no longer be derived for each application but can be adopted directly as the first step in design. With one relay for each input lead, the chain will establish an output corresponding to the lowest numbered operated

relay for any combination of relays operated. The input lead which is always served when its associated relay is operated is said to have the highest preference, and the transfer chain is often referred to as a preference chain.

The make connected transfer chain is used in cases that require the circuit to serve the lowest numbered input lead that is not grounded, as shown in Figure 19-3.

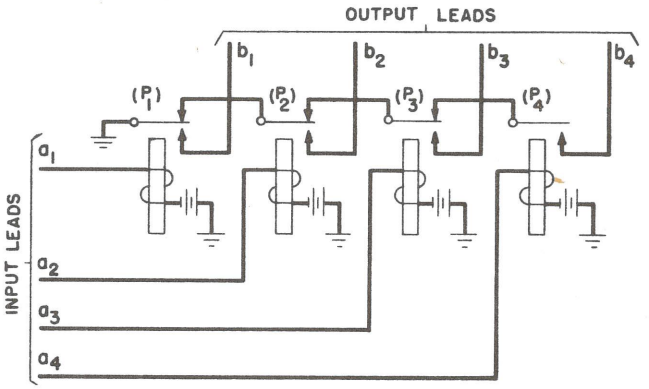


Figure 19-2 Break Connected Transfer Chain Fulfilling Requirements of Figure 19-1

19.3 COMMON SEQUENTIAL REQUIREMENTS OF POSITIONAL CIRCUITS

It has been indicated that where positional circuits are used it is usually impractical to consider each input combination and sequence individually. As a result, with these circuits the requirements for the establishing of outputs with respect to the sequence of input appearances must be of a general nature. Two common requirements related to input sequences are described below:

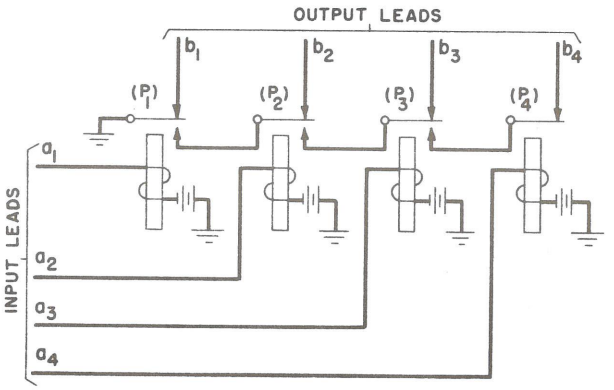


Figure 19-3 Make Connected Transfer Chain

1. Prevention of "Stealing"

When the preference chain is used by itself in a circuit application, service is given without regard to sequence of input appearance. If, therefore, an output condition has been established for one input and a higher preference input appears, the circuit will immediately drop the first output and establish a second output corresponding to the higher preference input. This "stealing" of the output condition by another input may interrupt an associated circuit in the middle of its action if it is not prevented.

2. Prevention of "Monopolizing"

Even with stealing prevented, a positional circuit may still have properties which are undesirable if the circuit always next serves the grounded input lead with the highest preference. When input leads are grounded again a short time after they have been served, those leads lower in preference may not be served for

long periods of time, while the high preference leads are served many times. This monopolization of service results in unequal use of the associated circuits and must be prevented where it is undesirable.

19.4 DESIGN METHODS TO MEET SEQUENTIAL REQUIREMENTS

In order that sequential requirements may be met by positional circuits, it must be possible to state them in such terms that no reference is made to a specific input lead. Thus, the requirement that monopolizing is to be prevented can be stated by saying that no input lead is to be served twice while another input lead is grounded and not served, or that no input lead is to be served until leads of lower preference, with coexistent grounds, have been served.

The latter requirement may be satisfied by establishing an operation pattern for the preference relays such that no input ground may operate a relay if a relay of lower preference is already operated. Provision must be made, however, to insure that a preference relay already operated is not released by the operation of a relay of lower preference. These principles are illustrated by the configuration of Figure 19-4 in which any relay in operating opens the direct operate paths of all higher preference relays through an auxiliary relay. It is evident that

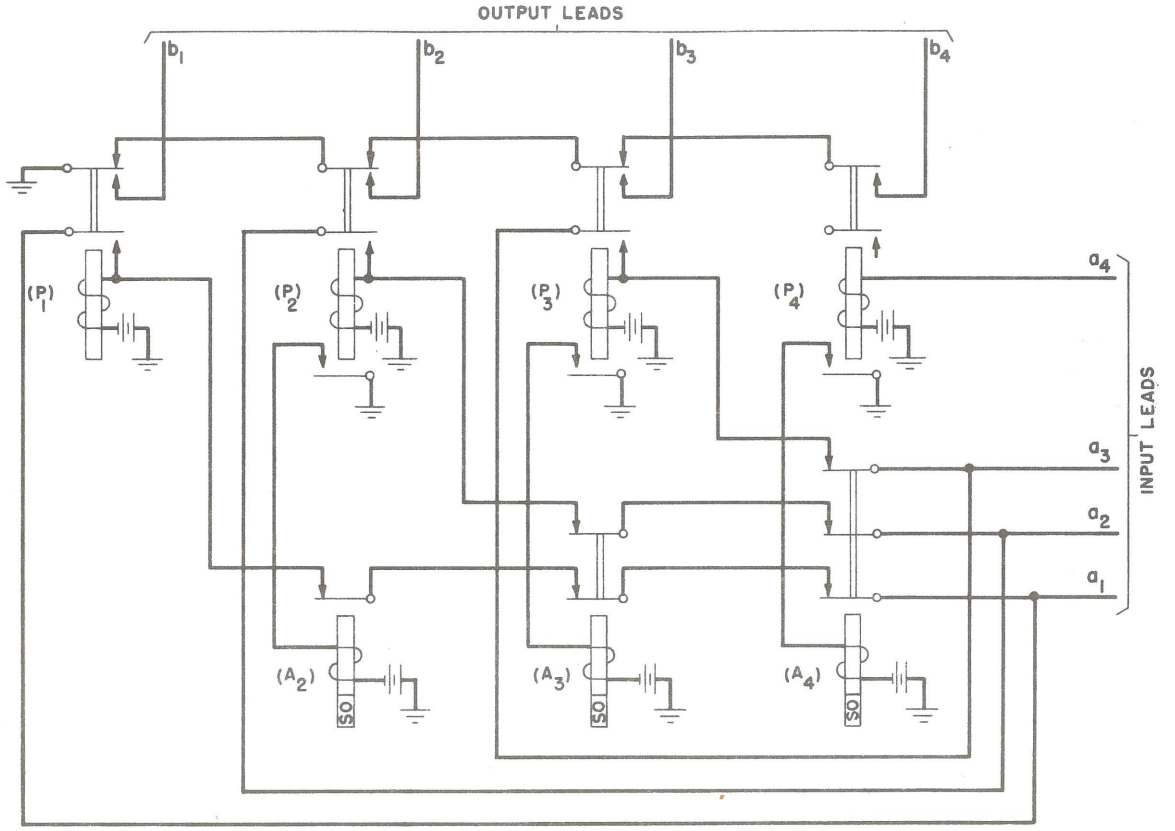


Figure 19-4 Modification of Figure 19-2 to Prevent Monopolizing

the spring pile-ups on the auxiliary relays are not even, the lowest preference relays being most heavily loaded. These auxiliary relays must be made slow in operating in order that when the lowest operated preference relay is released, all of the preference relays corresponding to grounded input leads are given time to operate before their direct operate paths are opened. Further circuit rearrangement and contact manipulation may equalize the load on the auxiliary relays or even eliminate them altogether.

With conditions for relay operation stated in terms of higher or lower preference relays, that is in terms of relay position, sequential relay circuit design techniques may be applied to design circuits with the desired properties. In doing this, only three relays of the preference chain need usually be considered: the two relays at either end and a typical intermediate relay. Except for the highest and lowest preference relays, all relays in the chain have identical contacts and connect identically to higher preference relays on one side and lower preference relays on the other. A general basic circuit, using the break connected chain, may then be considered as in Figure 19-5. When the additional contacts and relays have been determined to provide the proper sequential action of these relays according to stated requirements, the circuit may then be expanded to the required size by adding identical intermediate relays.

Any fixed cycle through which the circuit must pass in connection with each rendition of service will apply equally to all preference relays. The sequential circuit to provide the proper control of one preference relay in this respect may then be used in identical fashion for all preference relays.

In addition to requirements involving large number of possible input combinations and sequences, positional circuits are also applicable to long, fixed sequences in which some simple operation pattern obtains. Since the most common sequence of this nature is that of a train of pulses on a single input lead, for an example let us consider requirements calling for a circuit which will ground one of ten output leads corresponding to the number of pulses received over a single input lead. The circuit is to be capable of being returned to normal after any pulse by the removal of an "off-normal" ground.

In selecting the sequence of secondary relay actions to meet these requirements, a simple pattern must be maintained if a positional circuit is to be used. As seen in Chapter 18, different identifying relay combinations are needed both

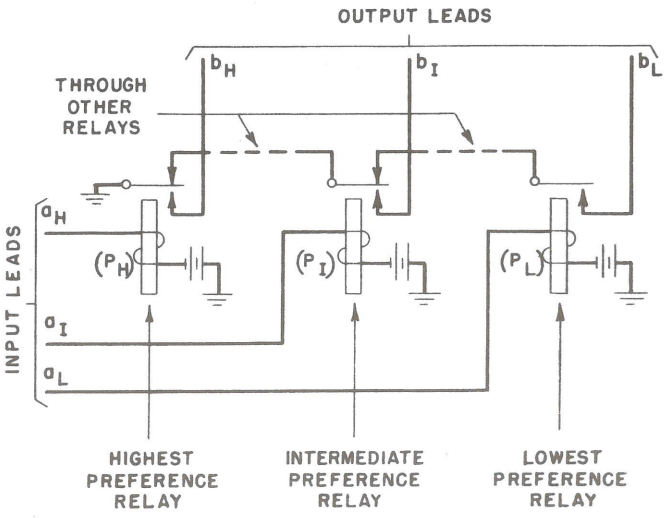


Figure 19-5 Basic Configuration for a Positional Circuit

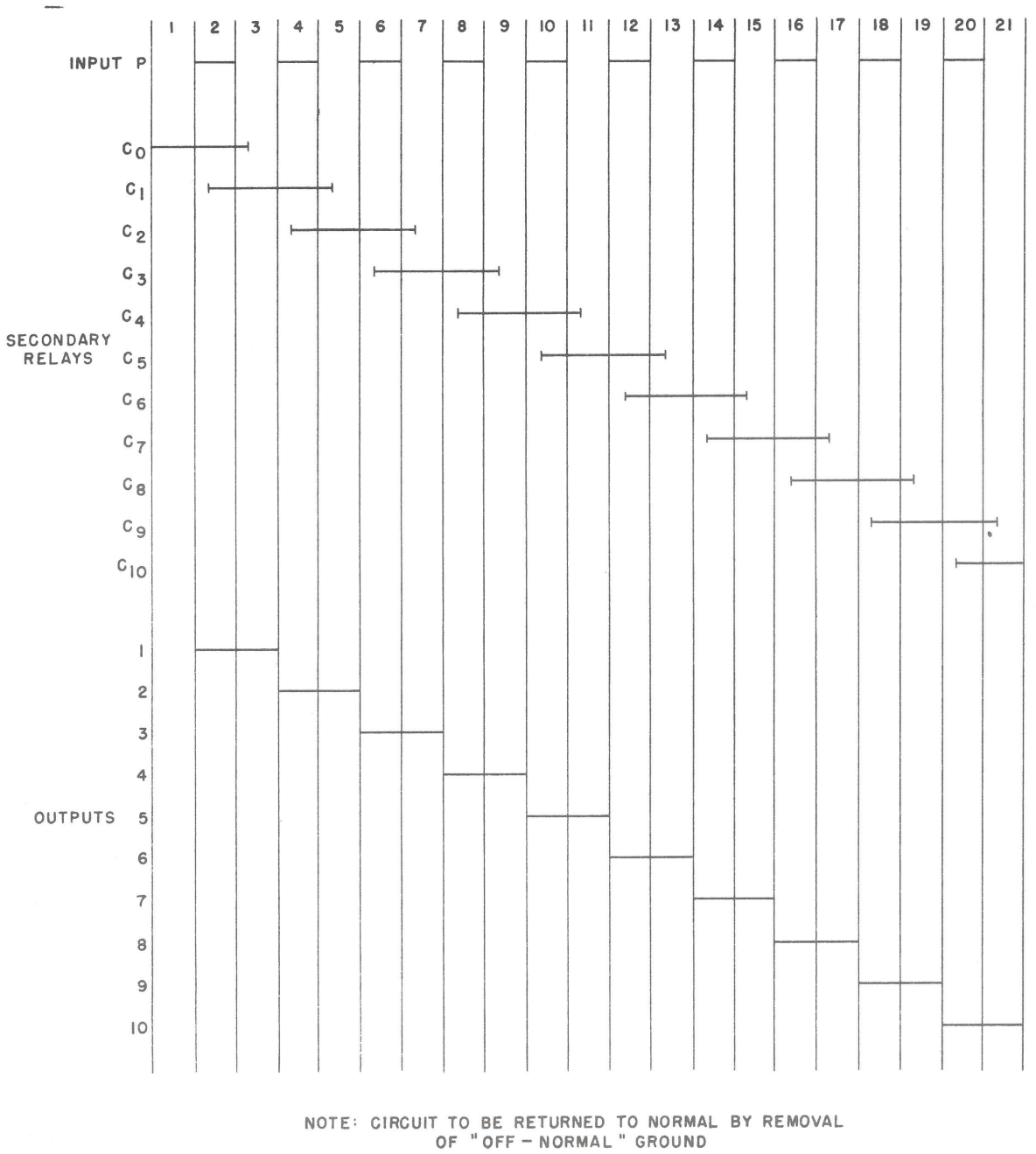


Figure 19-6 A Long Fixed Sequence of Inputs With Sequences of Secondary Relay Actions

during each pulse and in the intervals between pulses. The sequence of Figure 19-6 fulfills these requirements and the pattern of secondary relay actions is such that the conditions for operating any relay are easily described in terms of its position with respect to other operated relays.

Let us now determine the control path of relay (C_5), a typical intermediate relay, which may then be duplicated for the other intermediate relays. According to Figure 19-6, relay (C_5) is first energized when the input lead is grounded and the preceding relay (C_4) is still in the operated position, but the relays of lower number than C_4 are already released. A break connected transfer chain from the pulse lead (no primary relay is needed) through the lower numbered relays will then provide the operate path. When the pulse is removed, (C_5) must remain locked up to a network which will be opened when relay (C_6) is operated; this network may also be opened without any effect by the operation of any higher numbered relay. A break connected chain from "off-normal" ground through the higher numbered relays will then serve as a hold path. When the sixth pulse is applied and (C_6) operates, (C_5) must be locked to the input pulse lead so that it will release only when the pulse is removed. A single locking contact to the input pulse lead will serve here, provided care is taken to insure against back-up paths between this lead and "off-normal" ground. This is most easily achieved by using two-winding relays. The control of the relays at the ends of the chains is very similar to that of the intermediate relays. Control of (C_{10}) is identical except, of course, it locks directly to "off-normal" ground. (C_0) must be operated before the first pulse when all other relays are released. This can be done by letting the off-normal locking chain operate (C_0) through the series of break contacts on relays (C_1) to (C_{10}). This is shown in Figure 19-7 where the output conditions are established by means of a break connected transfer chain, similar to the "off-normal" ground locking chain.

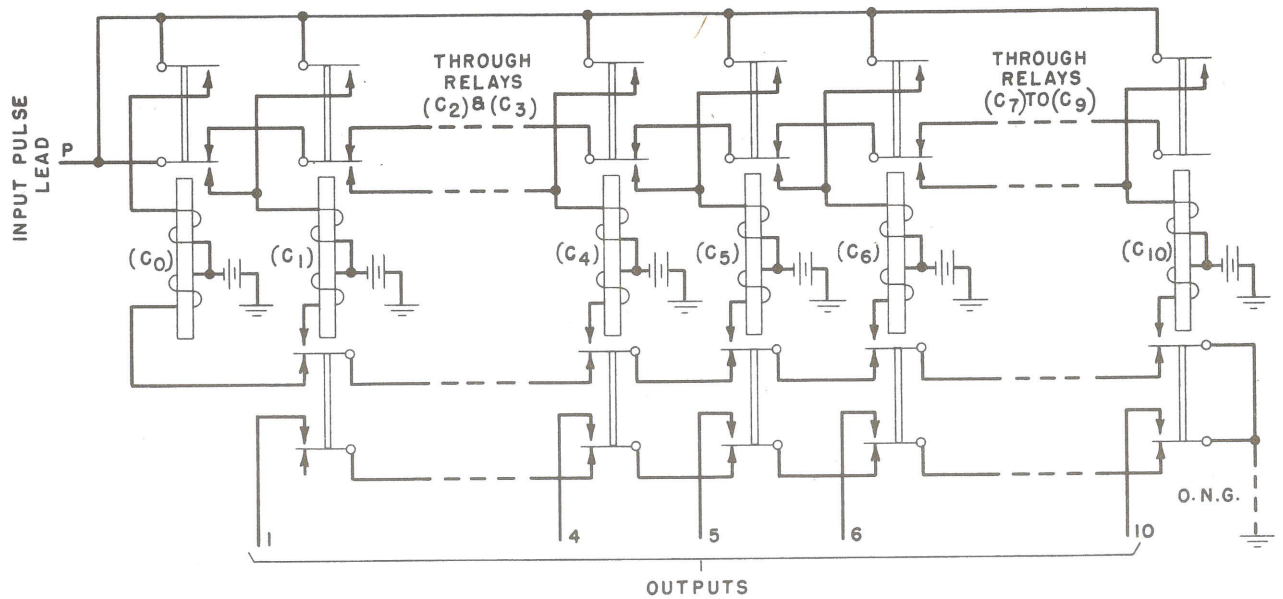


Figure 19-7 Positional Circuit for Sequence of Figure 19-6

CHAPTER 20

ELEMENTARY SWITCH CONTROL CIRCUITS

20.1 GENERAL

Some of the functions which must be performed in telephone switching can be most efficiently implemented by the aid of rotary and relay-type switches. This is particularly true of the task of establishing connecting linkages through switching systems—a major application for the crossbar switch, since the ratio of connectable contacts to electromagnetic control parts for this device is high. Then, too, the mechanical construction of a rotary selector switch makes its use as a sequence controller highly attractive. Switches find many other circuit applications throughout the field of automatic telephony.

As is found in the case of relays, certain basic switch circuits repeatedly make their appearance in the switching art, the particular configuration of circuit depending upon the type of switch employed and the function it is to perform. Switches occur in a wide variety of kinds, each of which demands particular consideration as to the best method of control.

In this chapter only the construction, operation, and control of the so-called rotary selectors and relay-type switches will be discussed. Such mechanisms as the panel and step-by-step selectors and power-driven rotary selectors will be left until the systems in which they are used are considered. The operation and control of these latter devices will present no difficulties if the rotary selector switches and associated control circuits are thoroughly understood.

20.2 MECHANICAL CONSIDERATIONS—ROTARY SELECTORS

Rotary-type selector switches consist, primarily, of arcs of terminals over which associated wipers pass. An electromagnet mounted on the switch assembly provides power to move the wipers from one terminal position to the next, each separate energization and deenergization cycle of the magnet causing the wipers to move one position. There are two basic types of rotary switches: forward-acting switches which step from one terminal to the next terminal on the energization of the magnet; and back-acting switches that step on the deenergization of the magnet. This control magnet of either type of switch is known as the "step magnet."

When the step magnet of a forward-acting switch is energized, a pawl coupled to the magnet armature is forced against the teeth of a ratchet wheel on the shaft

supporting the wipers, causing the shaft to rotate and the wipers to move from one terminal to the next. A detent engaging the ratchet wheel insures that the wipers remain on the terminal just reached after the magnet is deenergized. In the case of a back-acting switch, energization of the step magnet pulls a pawl away from the ratchet wheel on the wiper shaft, against the force of a spring attached to the frame of the switch. When the magnet is deenergized the pawl is pulled back by the spring, engaging a tooth on the ratchet wheel and advancing the wipers a single step.

Some rotary switches may be caused to step continuously in the same rotary direction over the same set of terminals, whereas others, after stepping their wipers over the associated arcs, must be returned to a normal position before the wipers can again be moved over the arc terminals. Switches of this second type are normally equipped with a second magnet, a release magnet, which removes a restraining detent from the ratchet wheel and allows a spring to restore the wipers to the starting position.

Wipers may be either of two types: bridging, in which adjacent arc terminals are short-circuited together by the wiper as it steps from one to the other; and non-bridging, in which the wiper leaves one terminal before it makes contact with the next.

Contact springs are often provided on the step magnet to indicate that the magnet is fully energized. Also, for those switches which must be returned to a normal position, off-normal contacts are employed to indicate when the switch is not in the starting position.

Illustrated in Figure 20-1 is a back-acting rotary switch consisting of six arcs of 22 terminals each. The wipers are double-ended so that when one wiper end has passed over the half-circle of 22 terminals the other end is in position to start stepping over the same 22 terminals. Occasionally, single-ended wipers mounted in pairs staggered 180 degrees apart are utilized on a similar switch so that two adjacent arcs of 22 terminals may be employed as a continuous bank of 44 terminals. The stepping magnet, in the lower left-hand corner of the picture, is equipped with a break contact. The switch may be driven by external circuit pulses at a rate of up to 25 steps per second, and 50 steps per second may be realized if the switch runs under self-interrupted control as discussed later in the chapter.

The circuit drawing conventions for such a switch are pictured in Figure 20-2. The bridging and non-bridging wipers are indicated by BDG and NBG, and the numbers in the center of the wiper circles are the arc numbers. The TH is the particular designation of the switch as used in some circuit. It is seen that, in actuality, there is a twenty-third terminal on the 22-position arc which is permanently connected to the associated wiper. This terminal merely serves as a means for joining external wiring to the wiper.

A forward-acting ten-terminal two-arc switch is illustrated in Figure 20-3. This switch is furnished with a release magnet, shown in the lower right corner, and off-normal springs, in the upper left corner. In the normal position the

wipers stand in the position just preceding the first terminal. The switch may be driven at speeds up to 25 steps per second and the maximum return-to-normal time (from the tenth position) is 0.250 second. Typical values of step and release magnet resistances are 155 ohms and 210 ohms, respectively.

As a wiper passes over its arc a second wiper connected electrically and mechanically to the first moves along a copper strip placed beneath the arc. This copper strip provides an electrical path to the first wiper and, for this purpose, is equipped with a wiring lug. Figure 20-4 shows drawing conventions for this switch.

20.3 CONTROL OF ROTARY SELECTOR SWITCHES

As discussed above, rotary selector switches are advanced one step for each cycle of energization and deenergization of a stepping magnet. The circuit which insures that the switch takes one and only one step per external control action is termed a stepping circuit.

Switching mechanisms are frequently required to step continuously, repeatedly recycling, when only a single external condition is present. This type of switch operation is known as "running" and the controlling circuit is then a running circuit. If a separate circuit action is employed to stop the running process at a specific

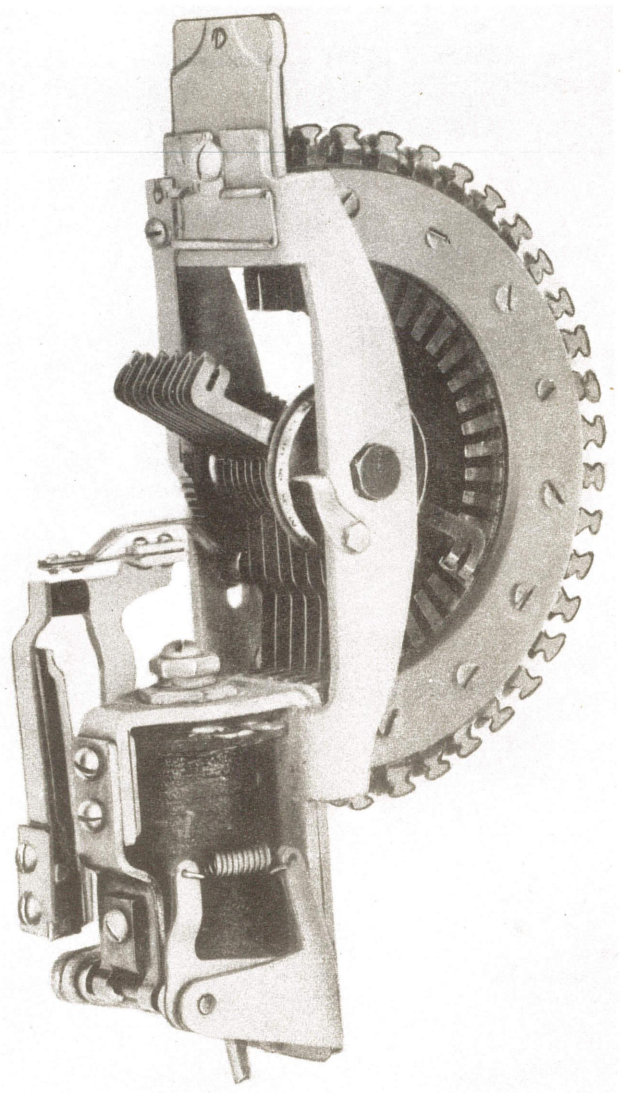


Figure 20-1 206-Type Selector

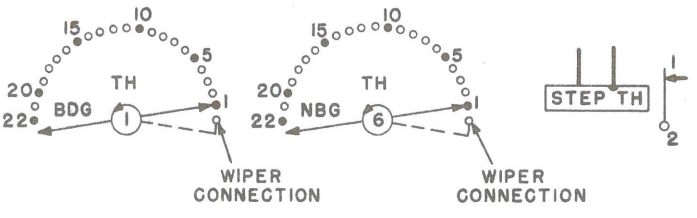


Figure 20-2 22-Terminal Rotary Selector Switch

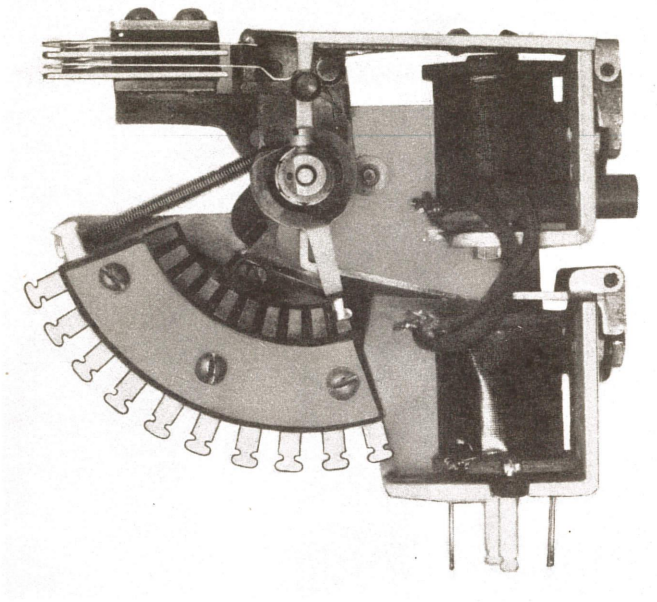


Figure 20-3 204-Type Selector

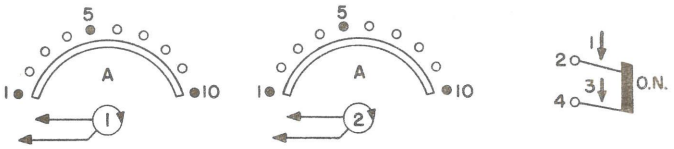


Figure 20-4 10-Terminal Rotary Selector Switch

time or switch position, the circuit providing the means for stopping the switch is referred to as a "halting" circuit.

Finally, it is often necessary, after a certain sequence of switch operations, to return the wipers of that switch to a starting, or normal position. This is accomplished by a restore-to-normal circuit which may either step the switch to the required position or operate a release magnet provided on the switch.

Any one of these control circuits is composed of one or more of the following elements: relays or other control devices external to the switch; contacts activated by the stepping magnets of the switch; and terminals of the switch arc and the associated wiper. The sections to follow indicate a number of methods by which rotary switches may be controlled in the stepping, running, halting, and restoring functions.

20.4 SWITCH STEPPING CIRCUITS

The most convenient method of stepping a rotary switch from one terminal to the next is that of directly energizing the step magnet until the pawl has reached its fully operated position and then deenergizing the magnet, allowing the pawl to return to rest. This may be accomplished by such a circuit as that shown in Figure 20-5, a direct stepping process in which the step magnet is energized by each closure of the make-contact on relay (P) in the external circuit. If the switch is of the forward-acting type it will step at the beginning of the ground pulse, whereas a back-acting switch will step after the step magnet is deenergized.

It may occur that the ground pulse applied by the external circuit to the switch is not of sufficient duration to operate the step magnet fully, and hence, would fail to step the switch. In this case it is necessary to lengthen the energizing pulse. This is effected by such an arrangement as the circuit of Figure 20-6. The input ground pulse operates relay (A) which locks to the break-contact on the step magnet. Ground is applied to the step magnet until relay (A) has

released, the release time of this relay insuring that the switch has fully operated. The adjustment of the contact on the step magnet also influences the duration of the magnet energization in that it should not open until the armature and pawl have been moved the required distance. The relay (A) may be made slow to release although this might retard the action of the circuit objectionably.

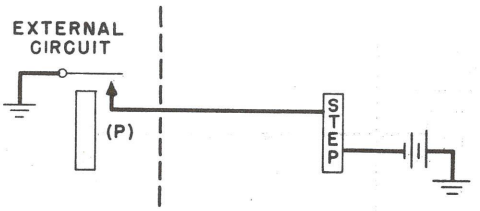


Figure 20-5 Direct Stepping

Conversely, the actuating ground pulse may be applied by the external circuit to the step magnet for a considerable time. Switch magnets are, in general, of low resistance to facilitate rapid stepping, and therefore, should not be energized for a time much greater than is necessary to permit the switch to step. For this reason, then, if such a condition does obtain, ground should be removed from the magnet winding by some action internal to the stepping circuit. One method by which ground may be removed after the switch has stepped is illustrated in Figure 20-7. Here, ground is applied to the switch only during the operate time of the slow-operating (A) relay. This relay may be replaced by any timing device which performs an identical function.

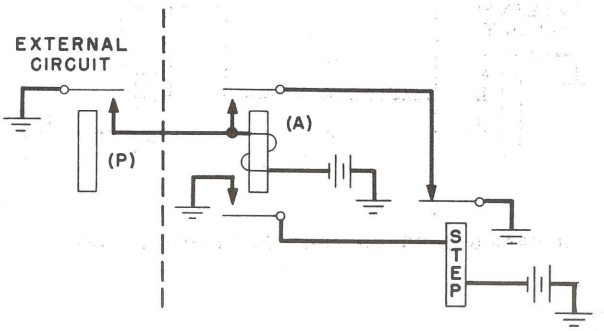


Figure 20-6 Control of Pulse Length—Pulse Too Short

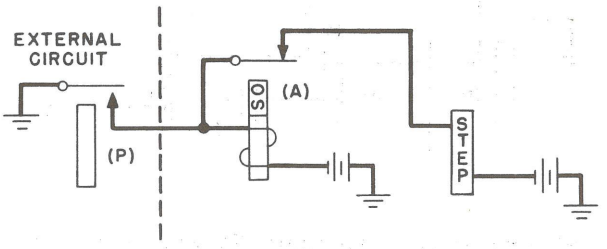


Figure 20-7 Control of Pulse Length—Pulse Too Long

In a given application, it may be necessary to step a rotary switch from a particular position to the next. This is accomplished by applying ground to an arc terminal in that position and connecting the step magnet to the wiper of the associated arc. The actual circuit used depends upon the type of switch employed; Figures 20-8A and B illustrate arrangements for forward- and back-acting switches. A break-contact is utilized on the step magnet for the back-acting switch to allow the switch to step while relay (P) is still operated. If the switch is in proper adjustment, this break does not open until the magnet is sufficiently energized to operate the pawl satisfactorily. It is necessary in the forward-acting arrangement that the detent pass

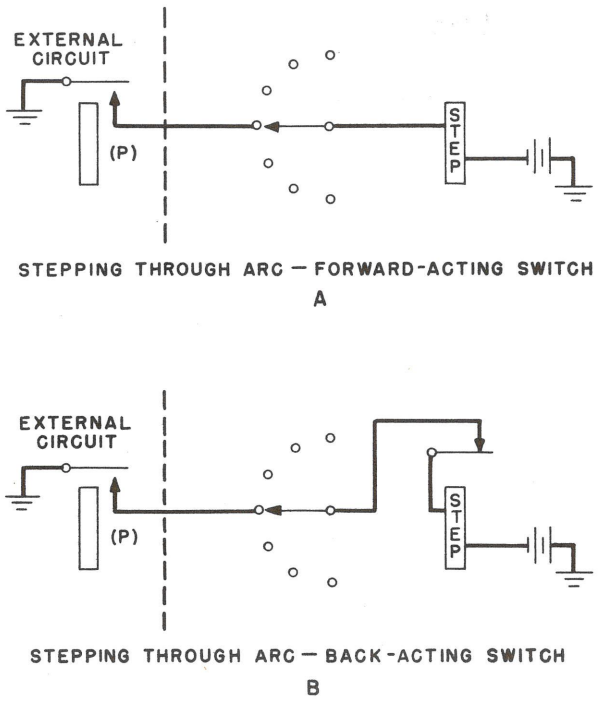


Figure 20-8 Stepping Through Arc

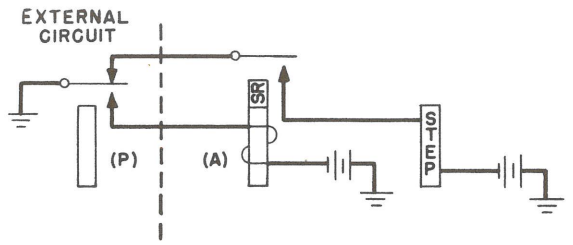


Figure 20-9 Stepping Forward-Acting Switch at Termination of Pulse

over the ratchet tooth before the wiper moves completely off the arc terminal which establishes the stepping magnet operate path. Switches are designed to meet these requirements.

A forward-acting switch may be made to advance in a manner similar to a back-acting switch, the wipers remaining fixed in position until the termination of the input pulse. A circuit making this possible is shown in Figure 20-9. The pulsing relay (P) of the external circuit operates slow-release relay (A), but when (P) releases, (A) remains operated for an appreciable time because of its release characteristics, closing the path to the step magnet. The forward-acting switch steps before (A) removes ground from the magnet.

20.5 SWITCH RUNNING CIRCUITS

In running it is necessary for the switch step magnet to continue to be energized and deenergized for as long as an external ground signal is applied to the input of the circuit or until the switch is halted. The most frequently used running arrangement is the "self-interrupted" type of circuit in which contacts on the stepping magnet structure are employed to indicate sufficient energization and deenergization for switch operation. These contacts, which close or open on each activation of the magnet are known as "interrupter" contacts, since in a self-interrupted circuit, they are used to interrupt the flow of current to the magnet. It is normally assumed that these contacts will act only when the pawl and detent are in the proper mechanical relation to the ratchet wheel to insure complete operation of the stepping mechanism. However, such factors as inertia of the armature assembly may permit the contact to be effective in a self-interrupted arrangement even though the mechanical relationship is not perfect.

The basic self-interrupted running circuit, illustrated in Figure 20-10, uses a break contact in series with the magnet winding. When the magnet has been

energized to an extent sufficient to actuate the switch, the energizing path is opened and the pawl assembly returns to normal, completing the cycle by reclosing the interrupter contact. This arrangement is applicable to both back- and forward-acting switches. In such a direct running circuit some switches may attain a speed of 50 steps per second, since full energization and deenergization of the magnet for each step is not necessary.

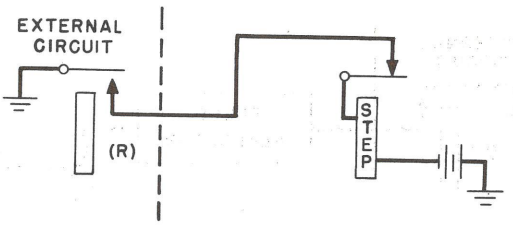


Figure 20-10 Direct Running—Self-Interrupted Circuit

Such rapid running may be undesirable, particularly if the switch is to perform functions at certain positions during the running process. If an additional relay is included in the circuit, the acting time of this relay can be added to that of the step magnet for each stepping cycle. To illustrate, two circuits are shown in Figure 20-11, one employing a make interrupter contact and the second, a break. In Figure 20-11A, the step magnet operating path is not opened immediately after the magnet has been energized, but instead, remains closed during the operating time of relay (A). After the operating path is opened, it is not again closed until (A) has released. If the spring load of relay (A) is light, its release time will ordinarily be greater than its operate time, and as a result, the switch, either back- or forward-acting, is deenergized for a greater duration than it is energized.

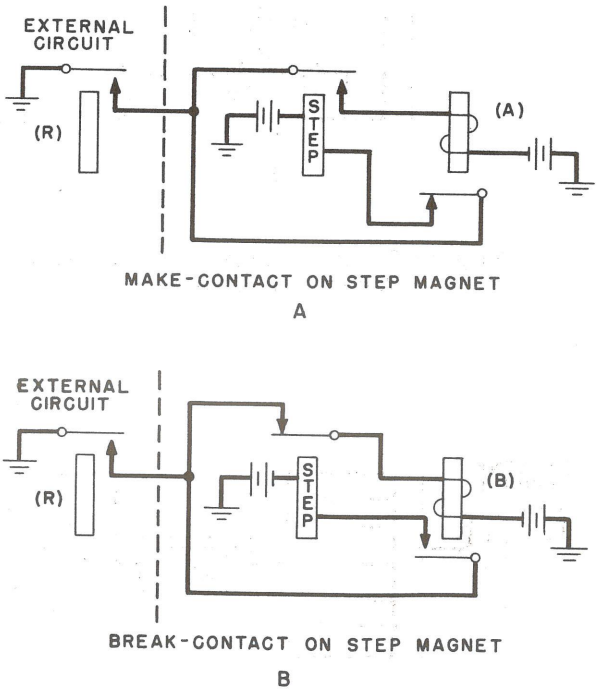


Figure 20-11 Slow Running

If only a break interrupter contact is available, an arrangement similar to that of Figure 20-11B is employed. Here, the period of magnet energization is longer than the period of deenergization. This may be a disadvantage in the case of a back-acting switch since, with such a type of switch, arc-terminal conditions are tested during the deenergization period. That is, if a condition on a particular terminal is to inform the back-acting switch to cease running when that terminal is reached, for example, information that the operating path is to be opened must be transmitted, and the opening of the path must occur all during the

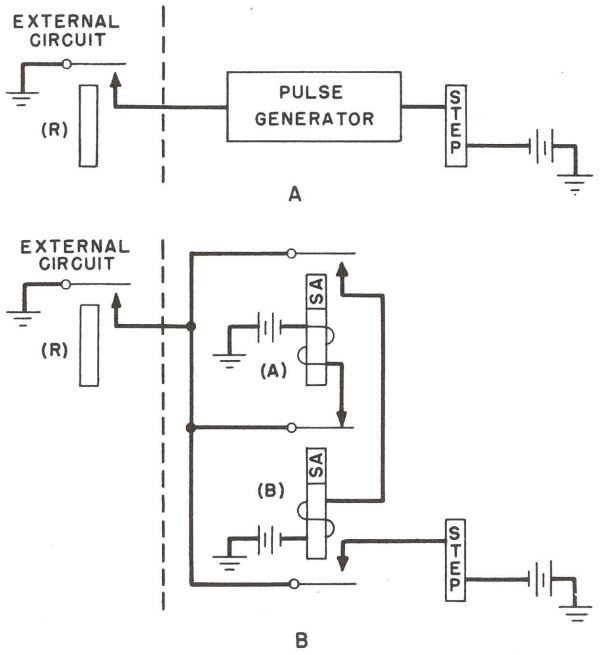


Figure 20-12 Running With Pulse Generator Control

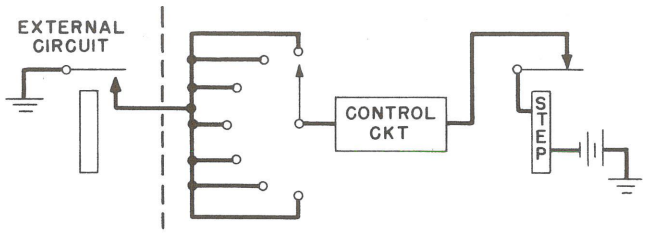


Figure 20-13 Running Through Arc

deenergization period which follows after the switch has reached that particular terminal. To increase this deenergization period, the relay (B) in Figure 20-11B can be chosen to be somewhat slow in operating; the circuit in Figure 20-11A can be similarly made slower running by selecting a slow-release relay for (A). It is normally of advantage, however, to permit the switch to run at as great a speed as is consistent with the requirements of the circuit.

An interrupter contact is not always available for running purposes, precluding the use of a self-interrupting circuit. In such instances, an external interrupter or pulse generator must be employed, as in Figure 20-12A. The pulse generator may be a motor-driven interrupter, a gas-tube pulsing circuit, or any other convenient pulsing arrangement. A switch controlled by a relay pulse generator is illustrated in Figure 20-12B. The slow-acting characteristics of the relays (A) and (B) limit the speed at which the switch runs. As in the circuits of Figures 20-11A and B, the release of relay (R) will immediately remove ground from the step magnet, preventing further running. Such direct control is desirable in that the progression of the wipers can be halted in the shortest possible time.

Often it is preferable to supply the running ground through a wiper and its arc, as in Figure 20-13. Any convenient running circuit may be chosen and the arc and wiper placed in series with the input control lead. If appreciable current is drawn through the arc, a bridging-type wiper should be selected in order to avoid contact damage caused by the making and breaking of the path at each step. This is specially applicable if the load on the arc is inductive as is the case in Figure 20-13 if the wiper is connected directly to the interrupter contact.

20.6 SWITCH HALTING CIRCUITS

The presence of a running circuit in the control of a rotary switch ordinarily implies that at some point the switch must cease to run. If there is included a method of halting the switch other than merely removing the input condition causing running, this arrangement assumes the form of a halting circuit.

In halting circuits means are provided for stopping the progression of the switch in some position as indicated by the presence or absence of a potential (battery or ground) condition on an arc terminal. In all the examples to follow the switches run to a terminal marked by the presence or absence of direct ground, it being understood that battery or some marginal condition may be substituted for the ground condition by appropriate circuit design.

One of the most useful of halting arrangements consists of a self-interrupted running circuit with the running ground passing through an arc and wiper of the switch under control. In the position or positions at which the switch is to be halted, the arc terminal is not connected to the external circuit ground. This basic circuit is illustrated in Figure 20-14. The arc terminals are protected by the use of a bridging-type wiper. In this figure, as well as in some of the others of this chapter, the switch arc is shown connected to ground and the wiper to the step-magnet circuit. However, if it seems desirable, these connections may be reversed. The current through the switch arc can be reduced by the addition of a repeating relay placed between the wiper and the interrupter contact, ground applied to the step-magnet circuit through a make-contact on this added relay. Used with a bridging wiper, this relay remains operated until the desired position is reached. The relay must be fast in releasing when the ungrounded terminal is found to prevent the step magnet from becoming energized for an additional step.

With the circuit of Figure 20-14 it is necessary to employ an additional switch arc and wiper to detect that the switch is in the halted position. This may be undesirable since all arcs are normally used to capacity; in such a case it would be convenient to provide means in the halting circuit itself to indicate switch stoppage.

A halt-indicating circuit for use with a forward-acting switch is shown in Figure 20-15A. Relay (S) is marginal in that it will release when connected in series with relay (H). The (S) relay is a part of a running circuit similar to that of Figure 20-11B. Relay (H) is locked down until the control wiper reaches the ungrounded terminal at which time it operates, removing the running ground from (S) and placing ground on lead "a" as an indication that the switch is halted. If a non-bridging wiper is employed,

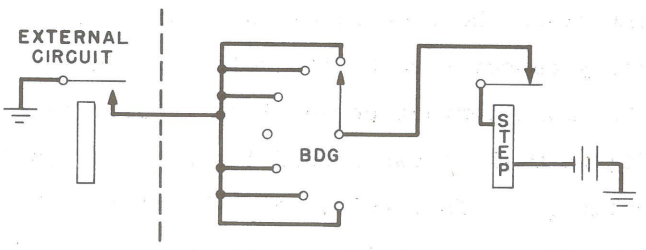


Figure 20-14 Direct Halting by Absence of Ground

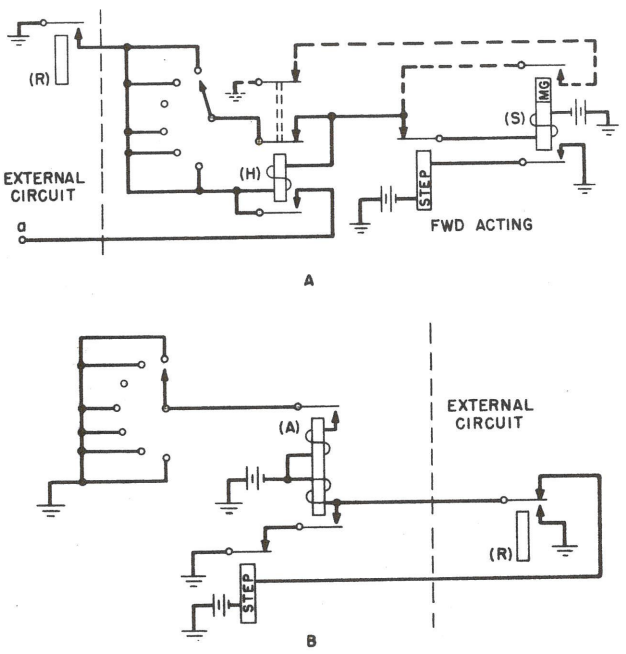


Figure 20-15 Relay-Controlled Running and Halting Circuits—Halting by Absence of Ground

the dotted wiring should be incorporated to insure that (H) will remain unoperated as the wiper passes between grounded terminals. A back-acting switch may be substituted in Figure 20-15A if the make on (S) in the dotted wiring is replaced by a break contact. For a forward-acting switch, relay (S) is operated during the wiper step movement; for a back-acting switch, (S) must be released before the switch can stop.

In all the running circuits previously mentioned, the operation of a relay (R), external to the running circuit, has provided the running ground. In the circuit of Figure 20-15B relay (R) must be operated and released before running can commence. Upon operation of (R), relay (A) operates and locks to the break interrupter contact of the switch. When (R) is released ground is applied to the step magnet which runs in self-interrupted fashion until relay (A) releases. Relay (A) can release only after the step magnet has been energized, the interrupter contact has opened, and the wiper has reached an ungrounded terminal. For a forward-acting switch these conditions hold when the wiper is in its halted position, but for a back-acting switch the wiper will be on the terminal just preceding the halting position. Thus the forward-acting switch will halt on the ungrounded terminal, whereas the back-acting switch will stop on the next adjacent terminal. In the circuit the wiper need not be of the bridging type since the locking path of relay (A) through the interrupter contact covers the interval during the wiper step movement. Relay (A), however, must be fast in releasing when the ungrounded terminal is reached since the interrupter contact in a rapidly self-interrupted circuit does not long remain open.

It is often more appropriate to halt a running switch on a grounded terminal since the running circuit can then be opened by the operation of a control relay rather than by its release. This is desirable since the control relay with its small contact-spring load is usually more rapid in operation than in release. Figure 20-16 shows a self-interrupted running circuit controlled by fast-operating relay (A). This relay acts when the marked terminal is reached, halting the switch and placing an indicating ground on lead "a". This is a widely-used circuit, especially in a form where the two connections to the arc and wiper of the switch in Figure 20-16 are reversed.

The control relay is not vital to a ground-halted circuit as is illustrated by Figure 20-17. Here, the step magnet is shunted down when the grounded terminal is reached, preventing further stepping. This circuit, however, gives no output indication of switch stoppage; and moreover, considerable current is drawn through the arc and the protective resistance.

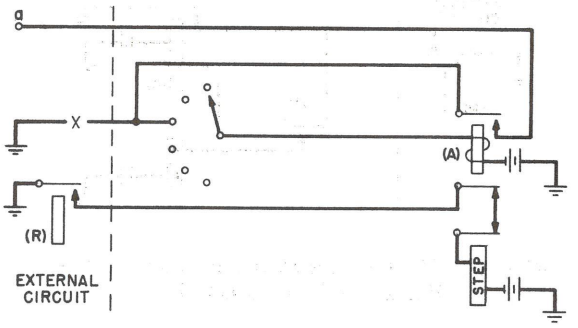


Figure 20-16 Basic Halting by Presence of Ground

20.7 SWITCH RESTORING CIRCUITS

As previously mentioned, rotary switches may be divided into two types: those which may be continuously driven in the same direction, cyclically passing over the same terminals; and those which, after stepping over their associated arcs, must be returned to a normal, or home, position from which they can again be stepped. Those of the first type are termed "non-homing" and the second, "homing" switches. Homing-type switches are ordinarily provided with a "release" magnet which actuates the restraining detent. A spring, which stores up energy as the switch steps from the normal position, is then allowed to restore the switch to normal.

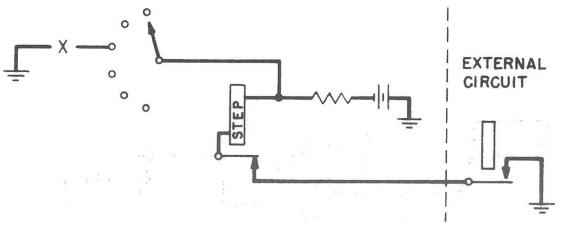


Figure 20-17 Halting by Presence of Ground—Shunt Operation

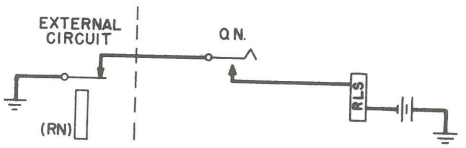


Figure 20-18 Basic Restoring Circuit—Homing-Type Switch

Whenever such a magnet is provided, a path (usually through a break-contact on a relay external to the restoring circuit) is closed when it is desired to return the switch to its home position. If the switch is off-normal at the time that the path is closed, the release magnet is energized and held energized until the switch has been restored to normal. A circuit effecting this is shown in Figure 20-18. Since the restoring ground is supplied through the off-normal contact, the release magnet draws current only until the switch is restored.

If the input ground from the external circuit is of insufficient duration to insure that the switch is fully restored, a circuit similar to that of Figure 20-19 or Figure 20-20 must be employed. The control relay (A) operates, supplying

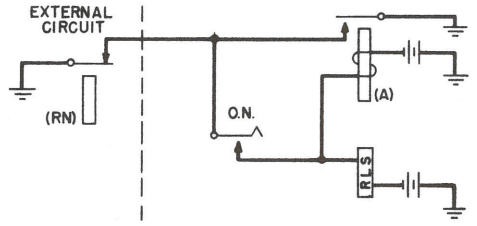


Figure 20-19 Restoring Circuit—Homing-Type Switch

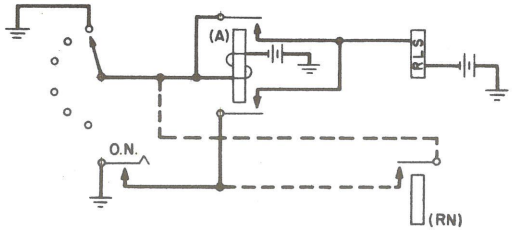


Figure 20-20 Arc-Controlled Homing Circuit

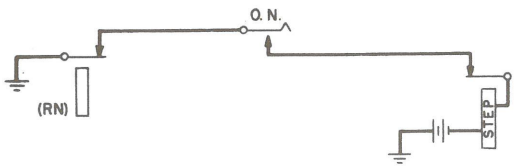


Figure 20-21 Off-Normal Contact Controlled Restoring Circuit—Non-Homing Type Switch

ground to the release magnet, and is locked operated until the off-normal contact is opened. It is important that the release magnet be held operated during the restoring action since the detent may damage the ratchet wheel if it is released during the restoring movement of the switch mechanism. Care must also be taken that the step magnet is not energized during switch restoration.

In Figure 20-20, the switch is returned to normal automatically when the wiper has reached its final position on the arc. Means are provided, however, by the circuit shown in dotted lines for restoring the switch to its home position at any time desired.

Rotary switches which do not have a mechanical normal position frequently require, for circuit reasons, the designation of a particular terminal as home. To reach this terminal, the switch is run through its arc and halted at the home position by some method similar to those already discussed. The circuit of Figure 20-10 is usually preferable as a result of its speed of action.

If a non-homing switch is equipped with off-normal springs, the off-normal contact may be used in restoring the circuit to normal. As in Figure 20-21, the switch runs in a self-interrupted manner until the off-normal contact opens.

Occasionally, an additional set of "off-limits" contacts are provided to indicate that the switch has reached the limiting position on its arc and must be returned to normal before the circuit can again function. When these contacts are actuated, the switch may be restored in a circuit similar to that of Figure 20-20, in which the wiper and grounded arc terminal are replaced by an off-limits make-contact. Rather than employing an

additional relay (RN) to restore the switch from any position, the switch can be stopped or run to the position where the off-limits contact closes.

20.8 MECHANICAL CONSIDERATIONS - CROSSBAR SWITCHES

The most modern switching systems in the Bell System use the crossbar switch as the basic switching unit. The characteristics of this switch as a piece of apparatus are discussed in a companion course on electromechanical switching apparatus. It is sufficient for the purposes of this text to point out that the elementary switching component of a crossbar switch is the so-called "vertical unit," which has one input and ten selectable outputs. The input—and hence the output—may include from three to six independent paths. The connection between the input and one of the ten outputs of a vertical unit is made by relay-like contacts which are actuated by the vertical or "hold" magnet. A complete crossbar switch may have up to 20 vertical units, with 200 outputs, which are referred to as "crosspoints." The selection of the particular output desired is accomplished by means of "select fingers," one per crosspoint pair, located on five horizontal bars which are actuated up or down by ten "select" magnets. To close a desired crosspoint, first the corresponding horizontal level is prepared by operating the associated select magnet, then the individual vertical magnet is operated, followed by the release of the select magnet.

Illustrations 20-22, 20-23, 20-24 show the complete switch and some of its mechanical details. Illustration 20-25 shows the circuit convention for the switch.

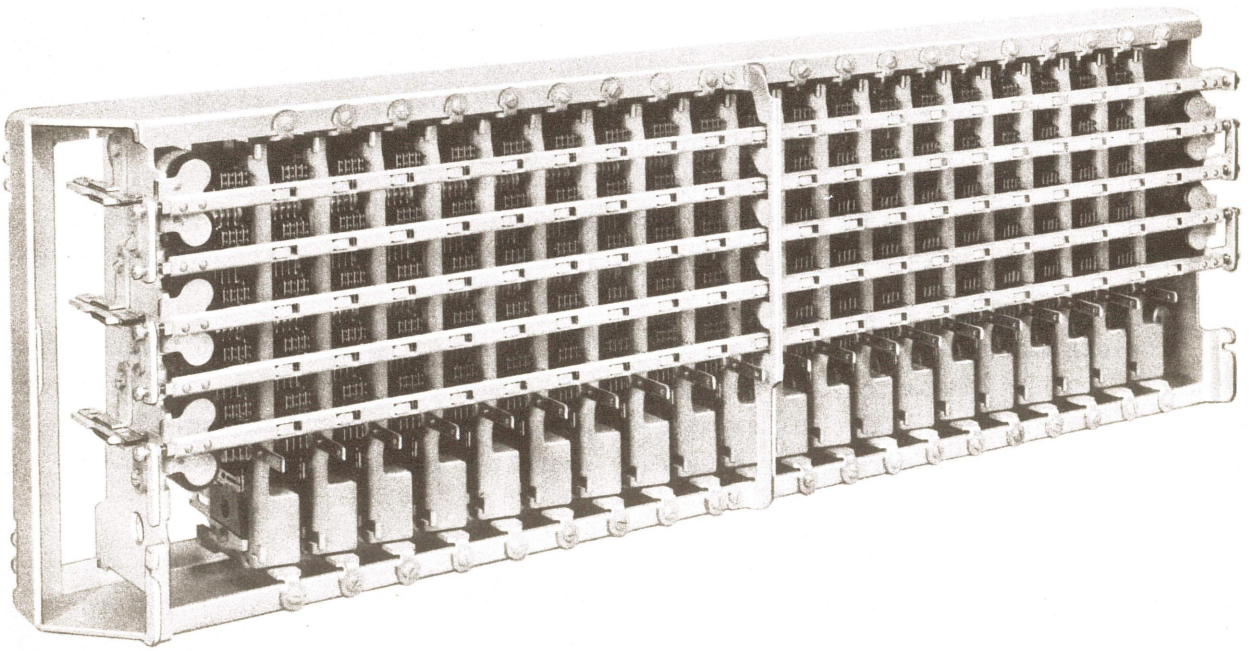


Figure 20-22 Crossbar Switch—Front View

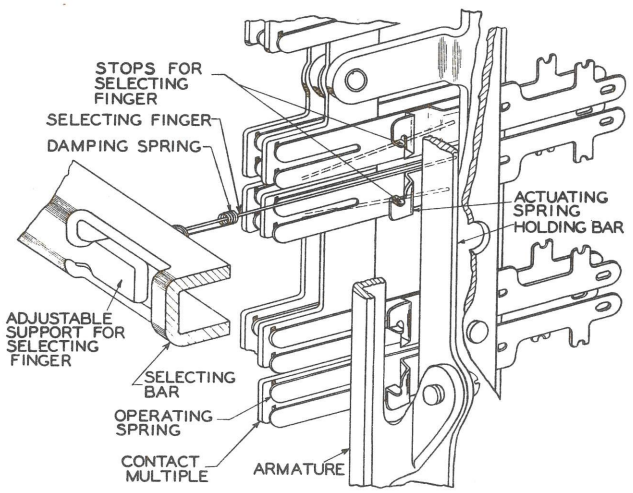


Figure 20-23 Crossbar Switch—Crosspoint Detail

20.9 CONTROL OF THE CROSSBAR SWITCH

The control of the crossbar switch is very similar to that of ordinary relays except that mechanical considerations dictate certain rules which must be followed in controlling the switch. Because of the construction of the switch, once a crosspoint has been closed and is held by its associated hold magnet, no other crosspoints in the same vertical unit can be actuated. More than one crosspoint in the same vertical unit may be closed only if the corresponding select magnets are operated before energizing the hold magnet. In this connection, it must be remembered that there are two select magnets for each horizontal bar and that only one of these should be energized at a time.

The operation or release of the horizontal bars results in transient vibration of the select fingers. For this reason time must be allowed in the circuit operation for the fingers to become reasonably stationary before attempting to operate a hold magnet, in order to insure against either missing a finger or "snagging" an extra finger when the hold magnet operates. Since each finger of a select bar, held by the vertical armature, exerts further tension on the bar, a limit of nine select fingers held on any horizontal level has been prescribed.

The hold magnets of a crossbar switch are usually energized for a considerably greater time than the select magnets since they hold the established connection. For this reason their windings are ordinarily of high resistance to conserve power. The operating time for a crosspoint, measured from the instant the circuit to the hold magnet is closed until the last contact of the crosspoint operates, varies from 0.026 second to 0.060 second, depending upon the number of contacts at the crosspoint and in the off-normal spring combination.

Select magnets, to be rapid in operation, are ordinarily provided with 600-ohm coils, though smaller values may be used, and are generally energized only for short periods of time. Time values measured from the closure of the select magnet circuit until the hold magnet may be safely energized range from 0.011 to 0.039 second.

To provide the necessary time between the operation of a select magnet and that of the hold magnet, various arrangements of delay circuits may be employed. These timing circuits may consist only of relays, or of relays in conjunction with condensers, gas tubes, and the like. An all-relay crossbar control circuit is shown in Figure 20-26 in which the operate time of the three relays in sequence is

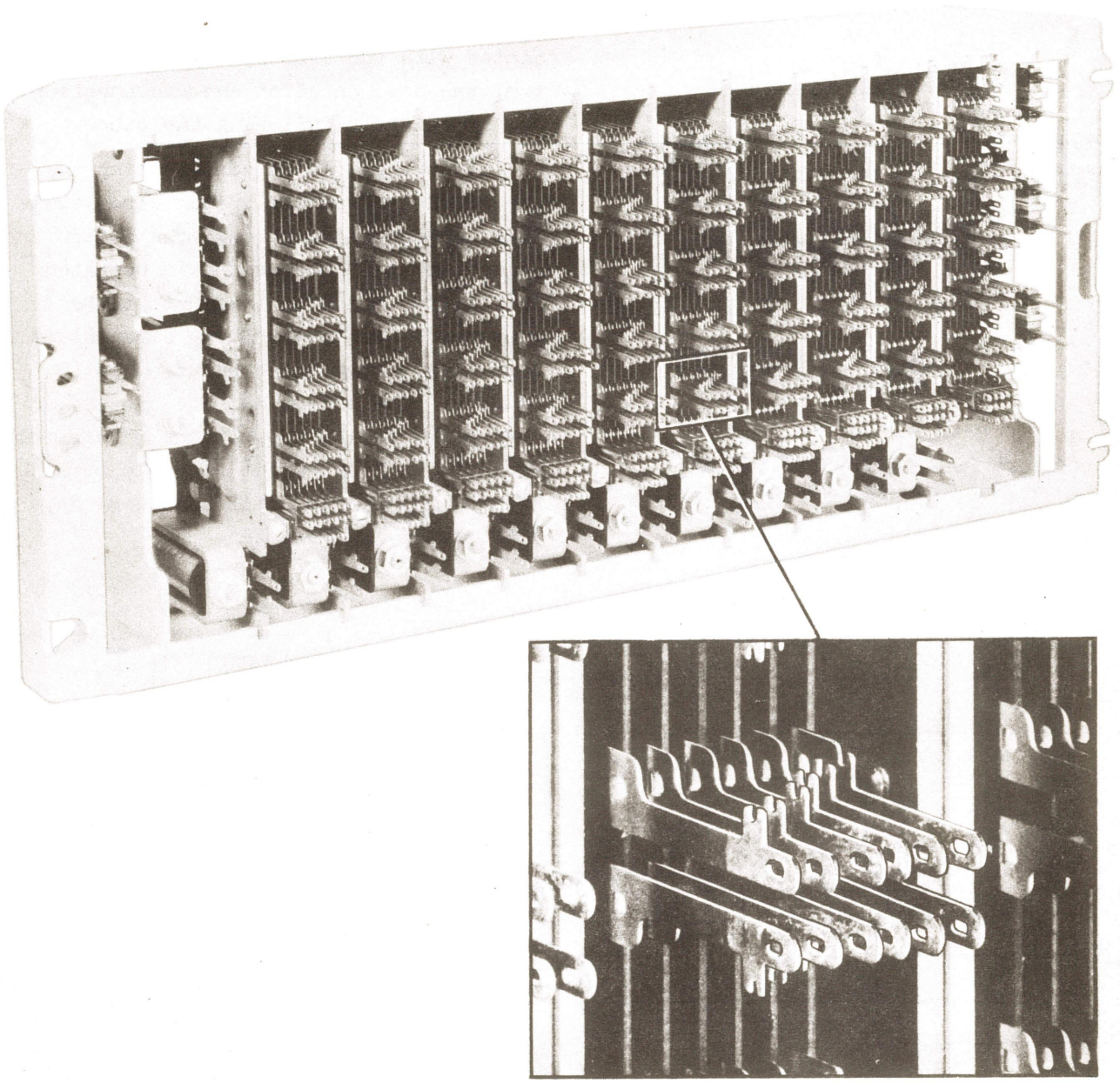


Figure 20-24 Crossbar Switch—Rear View

interposed between the operation of select and hold magnets. This circuit is self-checking in that it employs the locking contacts of both the hold and select magnets in its cycle of operation. Thus the circuit insures that the select magnet has operated before the hold magnet can operate and that the hold magnet has operated before the select magnet can release. Very often in elaborate circuits using crossbar switches it is possible to utilize the inherent time delays resulting from the performance of other functions to guarantee the necessary time interval, rather than providing specific relays for the purpose.

One of the principal advantages of the crossbar switch is that it is inherently more rapid in operation than the rotary-type switch. To disconnect an input from one output terminal and reconnect it to another, the rotary-type switch must move in a progressive manner over all intervening terminals. In accomplishing an

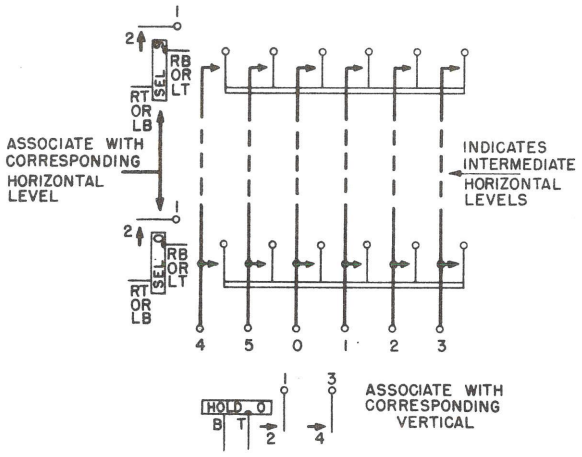


Figure 20-25 Crossbar Switch—Circuit Diagram Convention

identical task the relay circuit associated with the crossbar switch can control the disconnection and reconnection, one immediately following the other.

Another factor contributing to the speed of crossbar switch circuits is that no connection through the switch exists until a hold magnet is operated. This allows the select magnets to be operated by the controlling circuits at some time before the connection is to be made. The select magnets of the switch may follow the actions of control circuits with no effect on their associated crosspoints until such time as a hold magnet is energized.

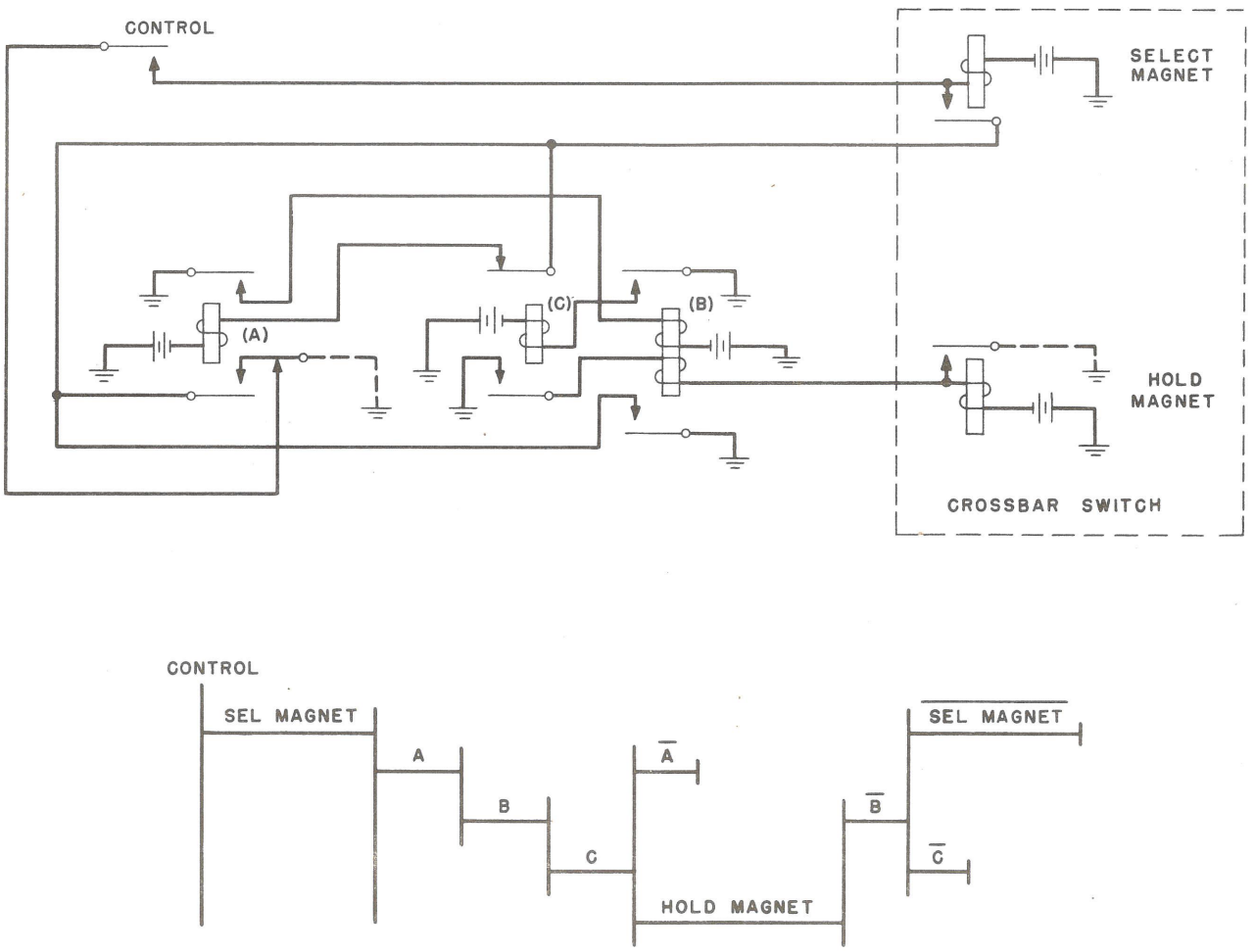


Figure 20-26 Control of Crossbar Switch Select and Hold Magnets

Although, generally, only one select magnet on a switch is operated to prepare for a connection, in certain applications two crosspoints must be closed to provide a path through the switch, thus usually necessitating the energization of two select magnets. An example of such a case is discussed in the following paragraph.

In normal operation the 100-crosspoint switch is equipped for 10 inputs, each with access to any one of 10 outputs. By reducing the number of leads in each output the number of outputs may be increased. Consider, for example, a six-wire switch of 100 crosspoints. Each vertical unit of six vertical multiple straps is divided into two groups of three straps each, as illustrated in Figure 20-27, thus effectively providing the switch with 20 crosspoints per vertical unit. Each vertical unit is equipped with one input which is connected to the "0" horizontal level associated with the first group of vertical multiples and also to the "1" level associated with the second group of vertical multiples of the same vertical unit. The crosspoints of the "1" horizontal level of the first group and the "0" level of the second group are left vacant. The remaining sixteen crosspoints of the unit each provide an output connection as shown in the figure. The outputs are multipled across all vertical units. By this device the switch has been altered to give sixteen outputs rather than the standard ten at the expense of reducing to three the number of leads to be connected. For any connection two select magnets must be operated as well as a hold magnet. To illustrate, if input leads "0" are to be connected to output leads "12", select magnets (1) and (6), and hold magnet (0), are energized. The particular hold magnet to be operated depends on the input lead, and the select magnets, on the output desired.

A more elementary method of switch division is that of separating the switch into two sections, each composed of half the vertical units of the switch. In this manner a "10 by 20" switch (200 crosspoints) may be made to replace two "10 by 10" switches with the slight restriction that the two sections cannot be allowed to set up connections simultaneously.

In practice, crossbar switches are generally used in conjunction with other crossbar

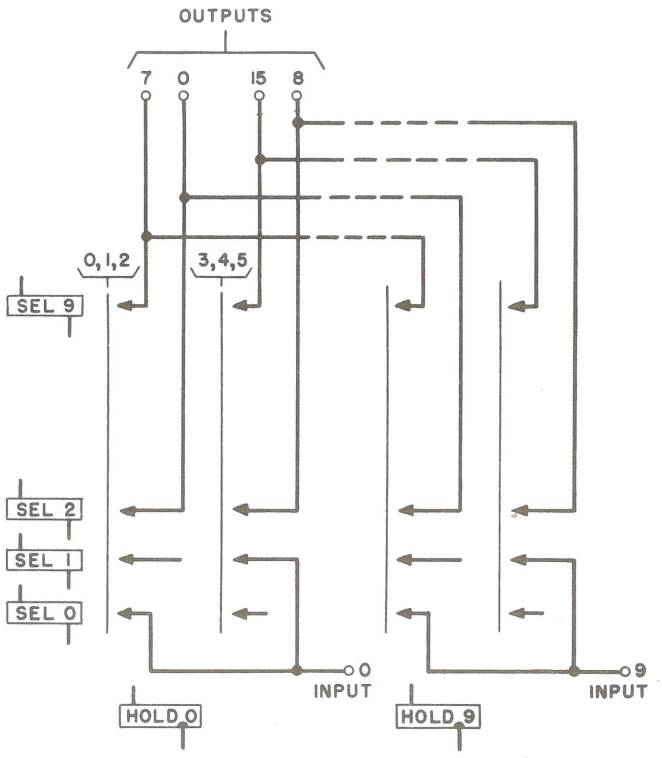


Figure 20-27 Splitting Crossbar Switch to Increase the Number of Outputs

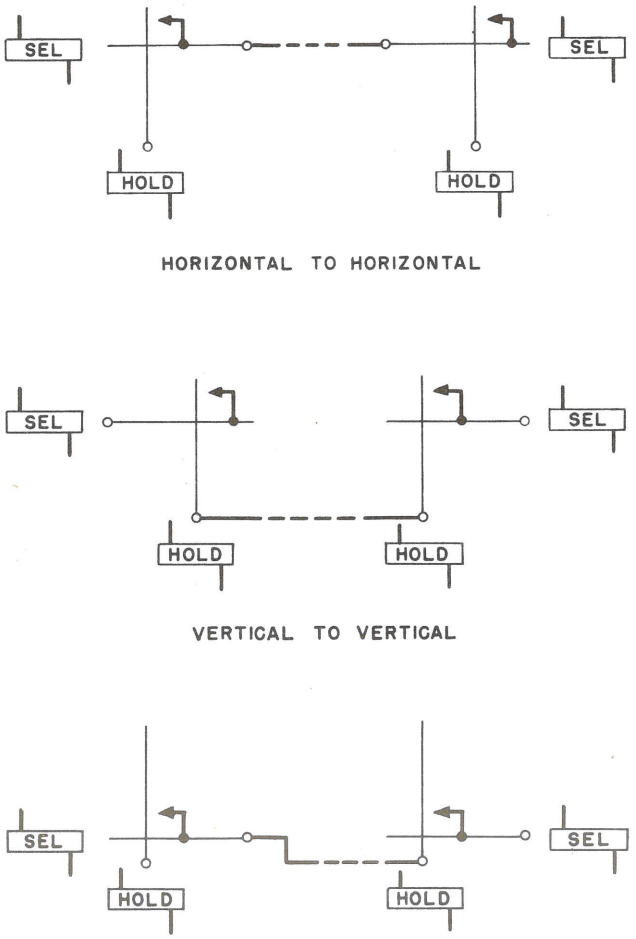


Figure 20-28 Three Methods of Interconnection of Crossbar Switches

switches. There are three possible interconnections shown in Figure 20-28: horizontal levels to horizontal levels, vertical units to vertical units, and horizontal levels to vertical units (or vertical to horizontal); and all methods are utilized.

In the design of control circuits for groups of connected switches it is only necessary to insure that select magnets are operated sufficiently in advance of associated hold magnets. It is often possible to connect the operating paths of magnets of different switches in parallel if it is determined that they are never to be used separately. For example, if horizontal levels of one switch are connected to horizontals of another, the associated select magnet windings may be operated and released in parallel. Similarly, the associated hold magnet windings may be connected in parallel if verticals are directly connected to verticals. The third method of interconnection, horizontal levels to vertical units, requires an only slightly more complex control. Select and hold magnets associated by the interconnection can not be tied together since after the connection through the switches has been made, the enabling select magnets, but not the hold magnets, must be released to allow the closure of other paths.

A common method of controlling this third arrangement of switch interconnection is indicated in Figure 20-29. The proper select magnet on each switch is operated, and ground is applied to one of the leads, usually the "sleeve" lead, to be carried through the switch network. This lead may be directly connected to the hold magnet on the first, or primary, switch, closing the crosspoints on this switch. Thus, the grounded lead is passed through to the second, or secondary, switch, and directly operates the hold magnet on this switch. Now, the select magnets may be released; the connection will be held as long as ground is connected to the "sleeve" lead. This method of holding an established switching path by the path itself is often employed.

Since the design of a crossbar switch control circuit depends primarily upon the function the switch is to perform and its relation to other associated circuits, detailed discussion of specific control arrangements will not be included at this juncture. However, no great difficulty in the understanding of such circuits is anticipated because of the previously mentioned similarity of the crossbar switch to a relay arrangement.

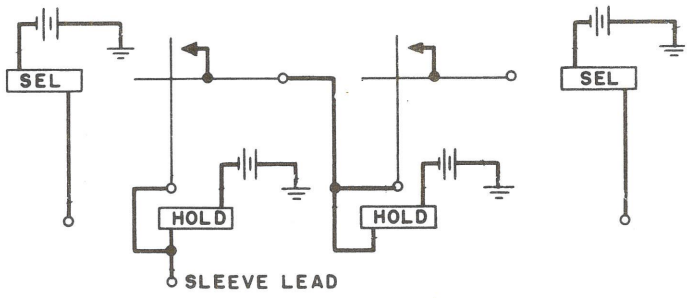


Figure 20-29 "Horizontal to Vertical" Crossbar Interconnection

CHAPTER 21

ELEMENTARY ELECTRONIC SWITCHING CIRCUITS

21.1 GENERAL

In previous chapters of this text considerable space has been allotted to the problems of basic relay circuit design. It should not be inferred, however, that the field of telephone switching is devoid of electronic devices. On the contrary, more and more applications are being found for which gas and vacuum tubes of various types are extremely suitable. In some cases, electron tube circuits can better fulfill the same functions which formerly were performed by relays; in others, tubes make possible entirely new methods of attack. The field of signaling, in particular, has benefited from electronic developments since with their aid frequency-, phase- and time-sensitive circuits are easily realizable.

Certain characteristics of electron tubes make them especially attractive to the designers of switching systems. Since tubes are high-impedance voltage-controlled devices, they are considerably more sensitive than relays which require comparatively substantial currents for their operation. Because of this characteristic the control of electron tube switching circuits may be carried out at low energy levels.

A second important quality of the electron tube for switching application is its speed of operation. As has been stated, speed is important to telephone switching systems for economic reasons in addition to its effect in the improvement of telephone service. To realize fully the benefits of increased speed obtainable with tubes, a system should be composed largely of electronic circuits or of circuits comprising tubes and high-speed relays (1 millisecond or less). Nevertheless, substantial advantages can be gained by utilizing electronic aids in circuits arranged for common use such as senders, registers, translators, and the like, because in these circuits speed can be readily capitalized.

As the preceding chapters indicate, relays in switching circuits may be called upon to perform tasks in accordance with requirements which may be in the form of a statement. For example, relay (R), in a certain situation, is to operate when relays (A) and (B) are operated or when relay (C) is released. Statements of this sort indicate the contacts which must be used on the circuit relays: makes, breaks, transfers, continuity-transfers, and the like; and also determine the plan of interconnection of these contacts. It appears that relays are peculiarly suited as means to the solutions of those circuit problems the requirements of which can

be stated in simple "and-or" form, although it is possible that more complicated switching circuit problems might be as conveniently solved by devices, such as electron tubes, the characteristics of which make them especially attractive in particular cases.*

It is possible to design an electron tube circuit which is equivalent to a given relay circuit or to a particular statement of requirements. Examples of tube circuits equivalent to series and parallel configurations of relay makes and breaks are indicated in this chapter. However, comparison of these tube circuits with the corresponding relay circuits shows that what is accomplished easily and simply by the relay circuit is performed with a much greater expenditure of circuit components by the equivalent tube circuit. Employment of the tube circuit can be justified as a direct replacement of the relay circuit only if the increased speed or sensitivity of the tube circuit is necessary or sufficiently desirable. Normally, it is more satisfactory to design a tube circuit, not as a relay circuit replacement, but as an entirely new solution to the switching circuit requirements.

Comparisons between relays and tubes on economic grounds are not, at present, universally in favor of tubes. The first cost of a gas tube which performs the functions of a general-purpose relay is greater than that of the corresponding relay, and the vacuum tube is somewhat more costly than the gas tube. More important, hot-cathode gas and vacuum tubes draw filament current continuously. Maintenance costs, on the other hand, are apt to be smaller for tube than for relay circuits since tube maintenance consists merely of test and replacement. However, depending upon operating conditions, the useful life of a relay may be greater than that of a tube, especially than those of a filamentary type.

As the previous chapters have shown, there are numerous specific methods for proceeding with the design of a relay circuit. Unfortunately, this is not true, in general, of electron tube circuits for switching circuit applications. The design procedure as well as the functional design of a tube circuit to perform a particular function depends more than that of a relay circuit upon the individual designer. This difference is due to the equipment with which the designer works. The tools of the relay circuit designer are relay contacts, which are either open or closed, and relay windings, which are either deenergized and energized. On the other hand, the tube circuit designer has a greater choice of circuit elements: tubes of many types, resistors, capacitors, inductors, thermistors, and so on. It should not be inferred from this that, due to the multiplicity of equipment available, the design of tube circuits is fundamentally more difficult, or conversely, less difficult, than that of relay circuits. It is true, only, that this multiplicity has retarded the formulation of basic methods for the interconnection of elements of a tube circuit in terms of circuit requirements. As a result, this chapter can only indicate a few tube arrangements which appear to be fundamental. The design of complete

*The "lock-out" is an example of a function which gas tube circuits can perform particularly adroitly as a result of the characteristics of the tube, as is discussed in a later course.

tube circuits which perform particular functions is deferred until a later course in which the design of functional relay circuits is also discussed.

In this chapter the theory of gas discharge, electron flow, and other physical phenomena related to the science of electron tubes has been omitted since it is assumed that the reader is familiar with the subject. A very limited summary of certain tube characteristics has, however, been included on the basis that the design of functional switching circuits takes advantage of these particular characteristics. The chapter emphasizes the use of gas tubes more than that of vacuum tubes. Such emphasis is, however, in accordance with the present status in telephone switching of the electronic switching art.

21.2 CHARACTERISTICS OF ELECTRON TUBES AS SWITCHING CIRCUIT ELEMENTS

Hot-Cathode Vacuum Tubes

The construction and characteristics of the many hot-cathode vacuum tubes in general use are well known. The output of such tubes as used in switching applications usually consists of a voltage condition on either anode or cathode, or a current flow in the cathode-anode circuit. This output depends upon potentials on one or more control grids which provide the means for setting up a particular output condition as a result of one or more input conditions. Two separate output leads, one from the anode and one from the cathode, can be furnished to external circuits and, when the tube is non-conducting, the two output leads are isolated. The vacuum tube may be used for impedance transformation, as in the cathode follower circuit for which the input impedance is high and the output impedance low.

Vacuum tubes are extremely sensitive and very rapid in response to control signals, their speed being dependent upon the small interelectrode capacitances and the electron transit time from cathode to anode. Unfortunately for some possible switching applications, a single vacuum tube cannot "lock operated" in the manner of a relay;* the control grid potentials must be regulated even after the tube has been operated. Also, the vacuum tube has the disadvantage of requiring either standby filament current or sufficient time to heat the cathode adequately before the tube is called upon to operate.

Hot-Cathode Gas Tubes

The hot-cathode gas tube is also capable of multi-control. Although the triode, the thyratron, is more familiar, there is in addition the hot-cathode gas tetrode equipped with two control grids. In accordance with the characteristics of gaseous discharge, large currents may be passed through the tube with low voltage drops. In this connection it should be noted that the life of a tube is a function of the time during which it conducts as well as of the magnitude of conducted current. The useful life, then, may be increased by allowing only low values of

*A non-conducting tube may be referred to as unoperated, and a tube passing current as operated.

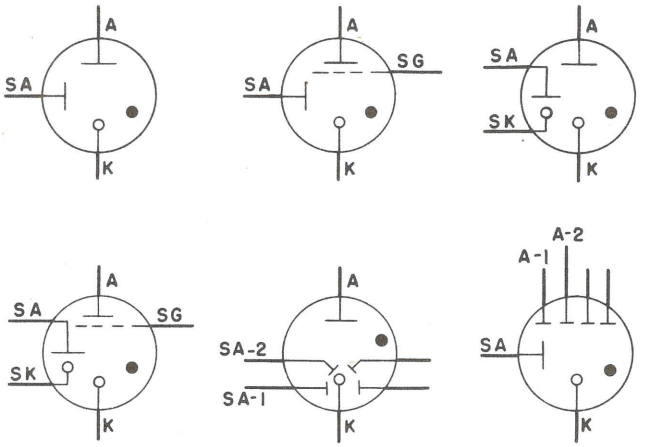


Figure 21-1 Representative Cold-Cathode Gas Tubes

current to be passed through the tube, or if high current is necessary, by permitting it to flow only momentarily. The hot-cathode gas tube, like the vacuum tube, requires standby filament current.

The speed of response of the tube is contingent primarily on the ionization and deionization times of the tube. Depending upon the gas, the ionization time ranges from a fraction of a microsecond to several microseconds; the deionization time is ordinarily of the order of 100 to 1000 microseconds, though lower values have been achieved. The tube, then, can respond very rapidly to input signals applied to operate the tube but considerably more time must be allowed for extinguishing the tube.

The hot-cathode gas tube is capable of self-locking; after it has been operated, or fired, the control grid loses control and the tube continues to conduct until a zero or negative anode-to-cathode voltage is applied to sufficient time to deionize the gas.

Cold-Cathode Gas Tubes

At present, the cold-cathode tube is the most attractive type of electron tube from the point of view of switching applications. There are many types of cold-cathode gas tubes, some of which are illustrated in schematic form in Figure 21-1, although the more intricate of these are only used when their particular advantages outweigh their greater costs. Those tubes with multiple main anodes provide for several outputs which are mutually isolated until the tubes fire; those with multiple starter anodes allow the tubes to be ionized by any one of several isolated input conditions.

Such properties as high sensitivity, low conduction impedance, self-locking, multiple outputs, and multicontrol pertain to the cold-cathode, as well as to the hot-cathode gas tube. Moreover, since the cold-cathode tube has no filament, no standby current is consumed. The speed of response, though somewhat less than that of the hot-cathode gas tube, is sufficient for most applications. The ionization time depends upon the time necessary to transfer the discharge from the starter gap to the main gap and is generally less than 100 microseconds. Main gap deionization times are of the order of 1 to 10 milliseconds. Because of its suitability to switching circuits, the examples contained in the remainder of the chapter are, in the majority of cases, based on the cold cathode-tube.

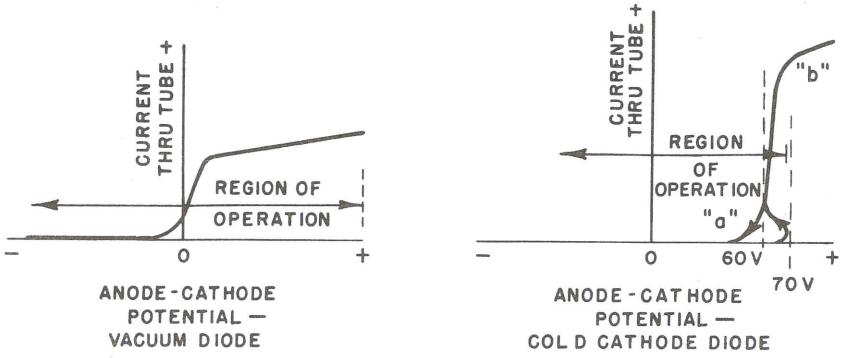


Figure 21-2 Characteristic Curves for Vacuum and Cold-Cathode Diodes

21.3 BASIC TUBE CIRCUITS APPLICABLE TO THE SWITCHING ART

Two-Element Tubes

A starting point in a discussion of basic switching tube circuits may well be the diode. As well as the familiar vacuum diode there are two-element gas tubes of the hot-cathode and cold-cathode types. Although these, fundamentally, are rectifying devices, the characteristics of the cold-cathode tube, in particular, permit its use for other applications.

Consider the characteristic curves shown in Figure 21-2. As these curves indicate, diodes are variable resistance elements exhibiting a high resistance over the range of anode-to-cathode potentials for which there is no conduction, and a relatively low resistance for potentials sufficient for conduction. The change in resistance occurs abruptly as a tube begins to conduct. The curves also show that for a conducting gas tube, within the operating range as determined by the allowable current drawn through the tube, the voltage drop across the tube is practically independent of the current through the tube. The vacuum diode, on the other hand, can be operated at voltages for which the current is essentially constant for changes in anode-to-cathode potential.

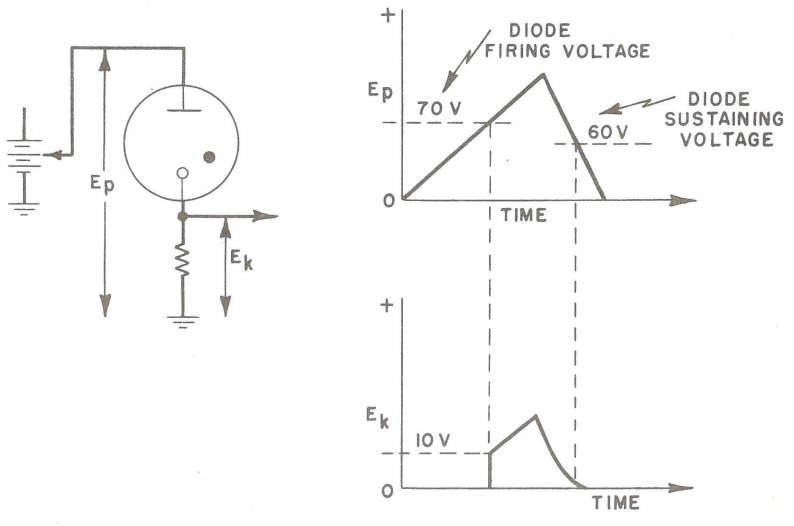


Figure 21-3 Operation of Cold-Cathode Diode

The most elementary cold-cathode diode circuit, shown in Figure 21-3,

consists of a tube in series with a load resistance in the cathode circuit and a variable potential applied to the anode. As the anode potential E_p is increased from zero in a positive direction, the voltage E_k across the load resistance remains at zero until E_p closely approaches the firing potential of the tube, about 70 volts for a representative cold-cathode tube. When E_p reaches this ionizing value, the tube conducts and, as the characteristic curve in Figure 21-2 shows, the potential across the tube is reduced to 60 volts. Since, at this moment E_p equals +70 volts, E_k is +10 volts. Thereafter, as E_p is increased from +70 volts, E_k increases by a like amount, the voltage drop across the tube remaining almost constant.

When E_p is reduced, the current through the tube diminishes until, at a very low value of current, the knee ("a" in the diagram of Figure 21-2) of the characteristic curve is reached and the voltage across the tube begins to decrease rapidly. This occurs at a value of E_p of slightly over +60 volts.

The relation between the anode voltage E_p and the cathode voltage E_k is indicated in the diagrams of Figure 21-3. Inspection of these diagrams show that the tube acts as a gate, allowing current to flow only during the interval in which the amplitude of the applied potential is adequate to fire the tube and sustain conduction. It is necessary that the resistance in the conducting path of the tube be high enough to prevent the tube from operating at the upper knee ("b" in the diagram of Figure 21-2) of its characteristic and be damaged.

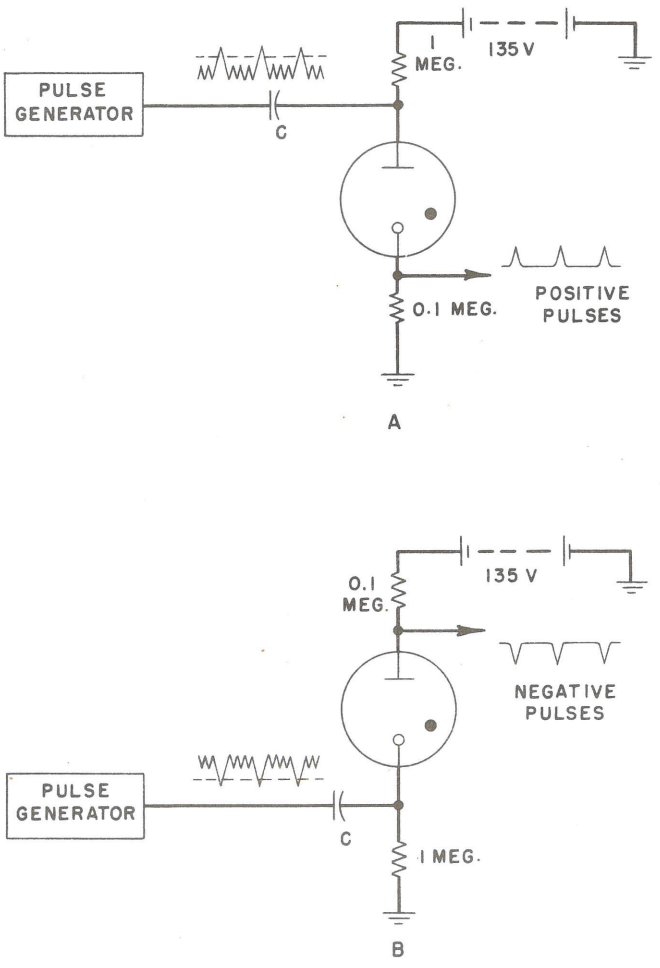


Figure 21-4 Pulse Gate Circuits

In practice this gate circuit is modified for use with applied pulses of short duration. The anode of the diode in the pulse gate arrangement, illustrated in Figure 21-4A, is supplied with a positive bias. Positive input pulses are applied to the anode through a condenser C which is large enough to retain its charge for the duration of a pulse. The amplitudes of the bias and the input pulses are such that the sum of the two is sufficient

to fire the tube. Since the anode and cathode resistances are high, the current drawn from the bias source through the tube is negligible. However, during conduction the additional current passing through the tube must be supplied by the source of the input pulses through the coupling condenser. Thus, if the capacitance of the condenser is too small, the tube current and the cathode voltage decrease by an excessive amount during the pulse interval. This drop, on the other hand, may be desirable in some applications. For adequately large values of C the waveform of voltage across the cathode resistor during the pulse is similar to that of the portion of the input pulse occuring during tube conduction. Irregularities in the input pulse waveform appearing while the tube is extinguished have no effect on the cathode waveform. Effectively, this pulse gate circuit clips the less positive portions of the input waveform, passing only the peaks.

A negative pulse gate circuit which removes the more positive portions of the waveform, operating on negative pulses, is shown in Figure 21-4B. This arrangement differs from the positive pulse gate circuit primarily in the values of the anode and cathode resistances. A negative input pulse applied to the cathode fires the tube, which conducts until the anode-to-cathode potential is reduced below the sustaining value.

Fluctuating voltages may be impressed upon both anode and cathode. For example, in the circuit of Figure 21-5 sinusoidally varying voltages 180 degrees out-of-phase are applied to the cathode of two diodes. Rectified alternating voltage, with the negative half-cycles removed, is applied to the two anodes which are connected together. This rectified voltage has the same frequency as that of the cathode voltages and is in phase with one or the other of these voltages. The voltage amplitudes are such that when anode and cathode voltages on one tube are out-of-phase, that tube will conduct once per cycle. The interval of conduction is a function of the amplitudes of anode and cathode voltages.

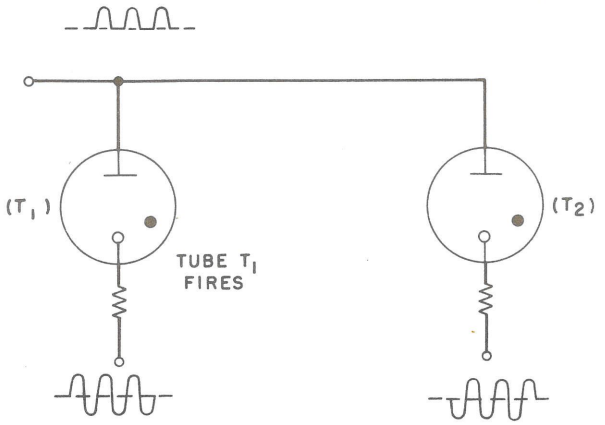


Figure 21-5 A-c Operation of Diodes

Three-Element Tubes

The three-element cold-cathode gas tube has, at the present time, probably greater practical application in switching circuit design than any other type of electron tube. This tube

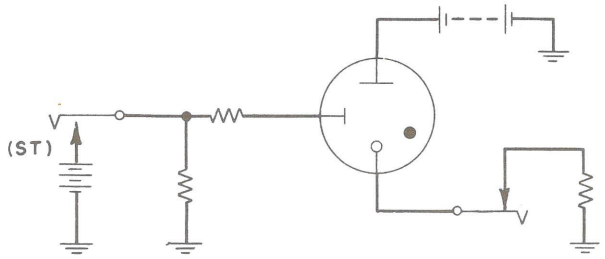


Figure 21-6 Operation of Three-Element Gas Tube

consists of a main anode and cathode, as in the diode, and, in addition, a starter anode placed close to the cathode. In the fundamental operating circuit of the tube, shown in Figure 21-6, the main anode is connected to a positive voltage source, and the cathode, to ground through a load resistance and a contact, or some other means, capable of opening the main anode-cathode conducting path. The main anode voltage supply is of a value lower than that necessary for ionizing the main conducting gap but greater than the main gap sustaining potential.

With the circuit at rest the starter anode is at ground potential. When a sufficiently positive voltage is applied to the starter anode, in this instance by the operation of the (ST) key, the starter anode-to-cathode gap is ionized, the discharge is rapidly transferred to the main anode, and the main conducting gap is ionized. After the main gap is fired, the starter anode exercises no further control until the tube is deionized. Main gap deionization is accomplished by reducing the main anode-to-cathode potential below the sustaining value. This is done in the circuit of Figure 21-6 by opening the conduction path through the cathode circuit, restoring the circuit to normal.

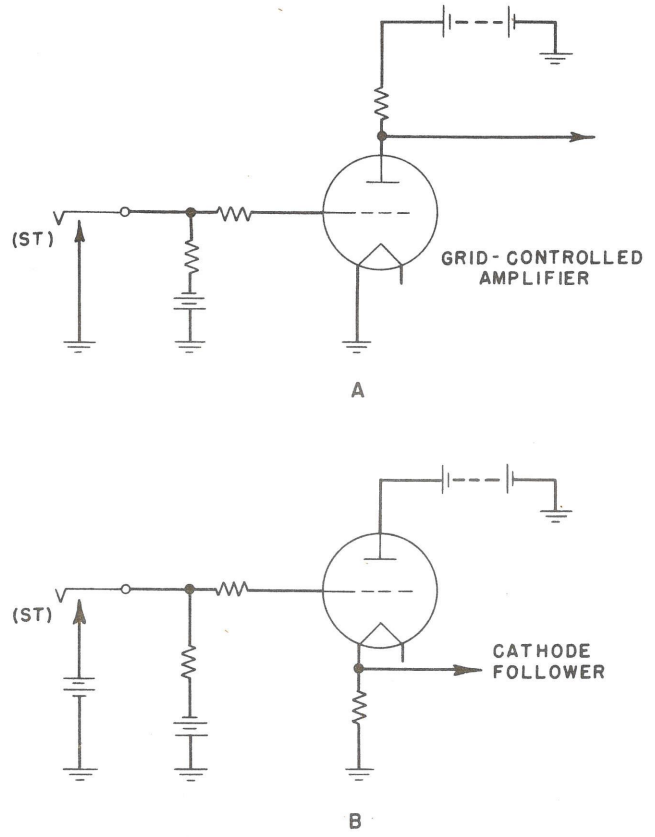


Figure 21-7 Basic Vacuum Tube Arrangements for Switching Circuit Application

The input to the cold-cathode tube circuit consists of a positive voltage condition, and the output either of a current flow through the load resistance or a potential measured across this resistance. Since the starter gap requires only a few microamperes for ionization, the source of the input signal may be of high impedance.

Vacuum triodes are also applicable to switching circuits under suitable conditions. The basic vacuum tube circuits, illustrated in Figure 21-7, are the grid-controlled amplifier and the cathode follower. Since the acting elements in switching circuits are usually required to be either operated or unoperated, the characteristic linearity of the vacuum tube is not normally of importance and the tube is considered to be in either of two states: conducting or non-conducting. In either of the two circuits of Figure 21-7 the tube is held in a cut-off condition by a

bias source until key (ST) is operated. The operation of this key raises the control grid potential to approximately that of the cathode. Thus, the tube is either highly conducting or cut-off, depending upon the control grid voltage.

The interconnection of electron tubes in a switching circuit is a problem the solution of which depends upon the requirements of the circuit and the ingenuity of the designer. Because of the multiplicity of possibilities it is impracticable to include in this chapter all the coupling networks which may be devised to connect two tubes. However, since certain fundamental requirements dictating the operation of tubes in a circuit appear often, it is convenient to have, as tools, networks fulfilling the requisites.

It is often necessary, for example, to extinguish one cold-cathode tube when a second is fired. This may be accomplished by connecting the cathodes of the two tubes together through a condenser, as in Figure 21-8. As shown, the starter gap firing voltage for these particular tubes is 70 volts and the main anode-to-cathode sustaining voltage is 75 volts. The starter anodes are biased at +60 volts. Note the similarity of the starter anode-cathode circuits in this figure to the diode circuit of Figure 21-4A.

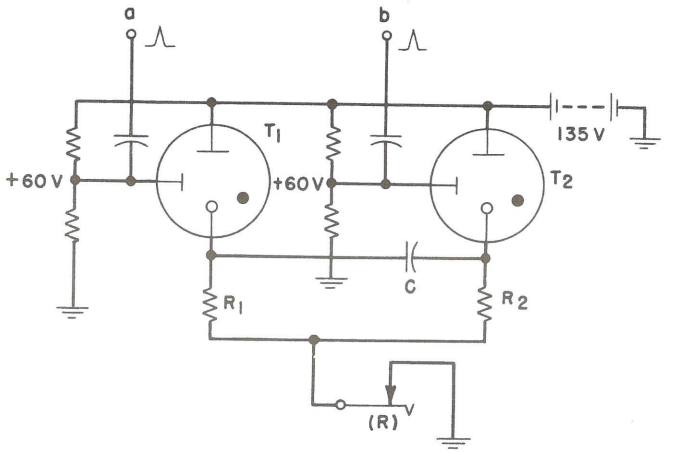


Figure 21-8 One Tube, in Firing, Deionizes the Second

A positive pulse of amplitude greater than 10 volts is applied to the starter anode of tube (T_1), for illustration, and the tube fires. Conduction current through resistor R_1 raises the cathode potential of (T_1) to +60 volts (since the sustaining voltage of the tube is 75 volts and the anode supply 135 volts). Due to the presence of condenser C the voltage across the resistor R_2 rises to +60 volts and then decreases exponentially at a rate dependent upon the value of C x R_2, C becoming charged to a potential of 60 volts. Some time after C has become fully charged, a pulse is applied to lead (b), firing tube (T_2). As (T_2) fires, the potential across R_2 rises to +60 volts. Since condenser C is charged to 60 volts, the potential across R_1 increases to 60 + 60 = 120 volts and tube (T_1) is extinguished. The cathode potential of (T_1) drops exponentially to 0 volts. Now, when tube (T_1) is again ionized, tube (T_2) is extinguished. It is necessary that after one tube is fired the charge on condenser C reach its steady-state value before the second tube is fired. The circuit may be restored to normal at any time by the operation of key (R).

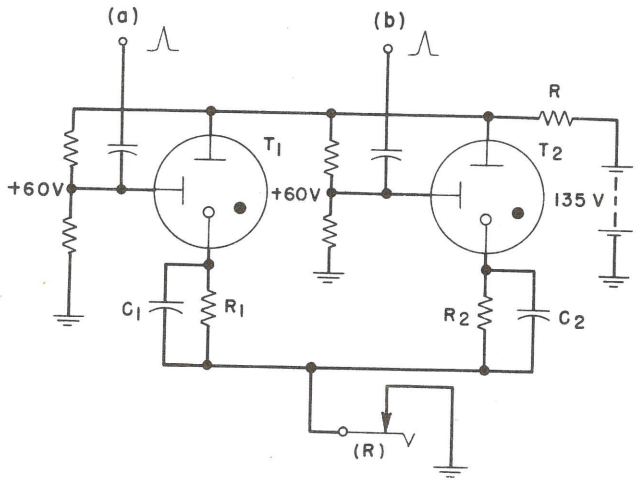


Figure 21-9 Another Method of Extinguishing One Tube When the Other Fires

A second method of deionizing one tube when a second is operated is illustrated by the circuit of Figure 21-9. Tube (T_1) is ionized by a positive input pulse as in the last example. Values of the common anode and the individual cathode resistances are such that after C_1 has become charged, the cathode potential is at about +45 volts. When the second tube (T_2) is fired, the initial drop across the anode resistance R is 135 -75 = 60 volts since C_2 is uncharged at the instant of firing. Thus, with its anode at 135 -60 = 75 volts, and its cathode held at 45 volts by C_1, tube (T_1) is deionized. The cathode potential of (T_1) then decreases to 0 volts as C_1 discharges through R_1, and that of (T_1) rises to +45 volts. When steady-state conditions are reached, the next operation of tube (T_1) will extinguish (T_2). Again the time duration necessary between actuating pulses depends upon the circuit time constants, in this case those regulating the charge and discharge rates of the two cathode condensers.

Another fundamental circuit action is that of holding one tube incapable of firing until a second has been operated. One method of accomplishing this is by causing the second tube to control the bias on the starter anode of the first, as in the arrangement of Figure 21-10A. In this circuit the bias on tube (T_2) is controlled directly from the cathode of (T_1). The value of this bias is either +50 volts or 0 volts depending upon whether (T_1) is conducting or extinguished. The input positive pulses have an amplitude of the order of 40 volts with the result that (T_2) can be ionized only if (T_1) has already been fired.

By a minor modification this circuit may be made to operate from a single input pulse lead, tube (T_1) firing on the first pulse and (T_2) firing on the second. In this modified circuit, shown in Figure 21-10B, a condenser is added across the cathode resistor of tube (T_1). As a consequence of this added condenser the bias on the starter anode of (T_2) rises exponentially toward +50 volts after (T_1) has been ionized. The capacitance of C is adequately large to prevent the bias from increasing during the application of the pulse to such a value that this first pulse can fire tube (T_2). By the time the second input pulse occurs, the bias on the starter anode of (T_2) is sufficient to allow this pulse to ionize (T_2). The circuit can be expanded to any number of tubes by connecting the starter anode of each tube to a tap on the cathode resistor of the next preceding tube, as (T_2) is connected to (T_1), and adding a condenser from cathode to ground for each tube.

The arrangements of Figures 21-8 and 21-10A may be combined to form a circuit in which the second tube cannot be fired until the first has been ignited, and when the second does fire, the first is extinguished. This circuit, shown in Figure 21-11, is somewhat similar in operation to the "W-Z" relay combination mentioned in an earlier chapter of this text. The first positive input pulse is applied to the starter anodes of both tubes but, since only tube (T_1) has adequate starter anode bias, tube (T_1) fires. As (T_1) ionizes, its cathode rises to +60 volts, the starter anode bias of (T_2) increases to +50 volts, and the cathode of (T_2), coupled to the cathode of (T_1) through condenser C, rises to +60 volts. Because this rise in cathode potential for tube (T_2) accompanies the increase in starter anode bias, the first pulse does not fire (T_2) after the ionization of tube (T_1). As in the previously discussed circuit of Figure 21-8 the condenser C charges before the second pulse, allowing the cathode potential of (T_2) to fall to zero. The second pulse fires (T_2) and, through condenser C, extinguishes (T_1). The third pulse fires (T_1) and extinguishes (T_2), and so on. Tube (T_1) is ionized by the odd-numbered pulses, and (T_2) by even-numbered pulses.

A characteristic of gas tubes which is of great importance to one functional circuit in particular, the lockout which is discussed in a later course, concerns the operation of tubes connected in parallel.

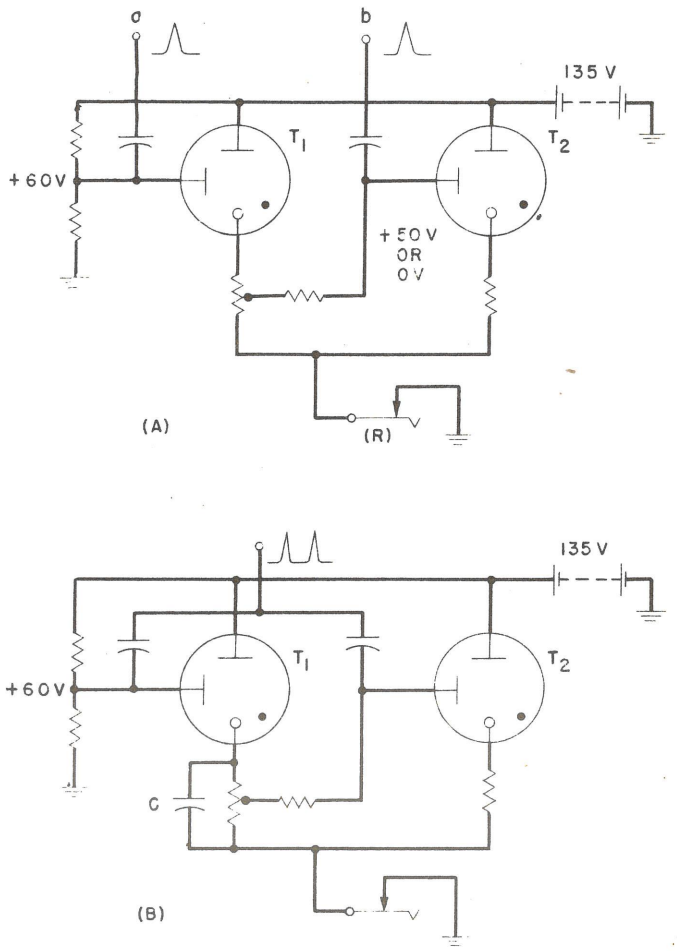


Figure 21-10 Second Tube Cannot Be Fired Unless First Tube Is Ionized

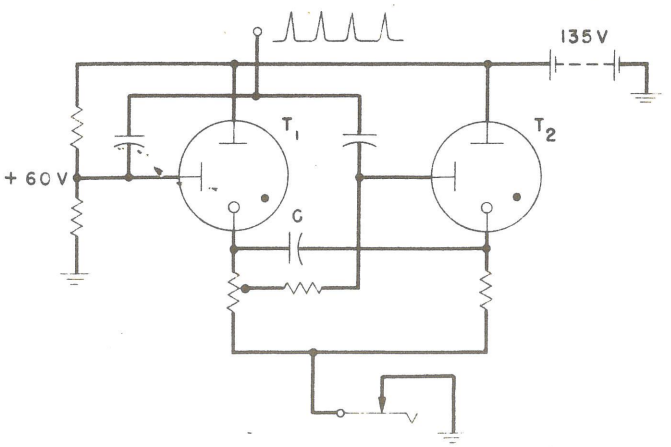


Figure 21-11 Odd-Numbered Input Pulse Fire (T_1), Even Pulses Fire (T_2)

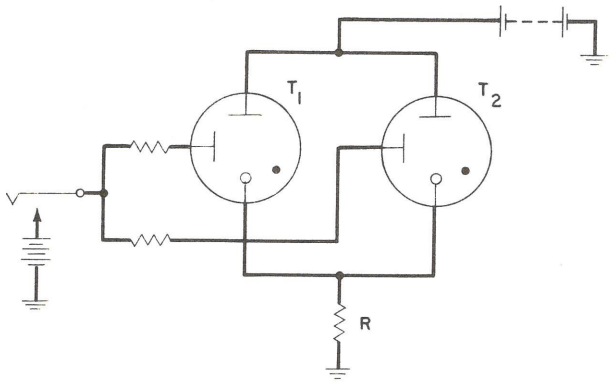


Figure 21-12 Two Gas Tubes With A Common Load Impedance

It has been found that if two or more gas tubes are provided with a common load resistance, as in Figure 21-12, either in the anode or in the cathode circuit, only one tube, except in rare cases, will ionize and remain ionized even if firing potentials are applied to the several tubes either simultaneously or in sequence. This phenomenon is due to the region of negative resistance in the characteristics of the gas tube through which the tube passes in the range between the breakdown and the stable sustaining voltages. In this region as the current through the tube increases, the voltage across the tube decreases, tending to prevent other tubes with the common load resistance from firing. However, if two tubes reach the breakdown potential simultaneously and then travel through this unstable region exactly together, it is possible for the two tubes to remain ionized, since in the stable condition of normal conduction the characteristics exhibit a positive resistance.

To reduce the slight possibility of this dual operation, the common load resistor is replaced by an impedance including an inductive element. The effect of the inductance is to increase the time interval necessary for the tubes to traverse the unstable region, thus decreasing the likelihood of the two tubes passing through this region exactly together. A second modification is that of employing multi-element tubes which ionize in successive stages, corresponding stages having common inductive impedances.

One such arrangement is shown in Figure 21-13. The tubes in this circuit have a separate starter cathode with the result that the starter gap firing circuit is isolated from the main anode-cathode gap. The tubes are fired in two stages: first, the starter gap is ionized, and then the discharge transfers to the main gap. In the circuit of Figure 21-13, the two tubes can be fired coincidently only if both pass together through the unstable region for each ionization: that of the starter gap, and that of the main gap. If the probability of two tubes traversing one such region is small, the probability of covering all such regions together is infinitesimal.

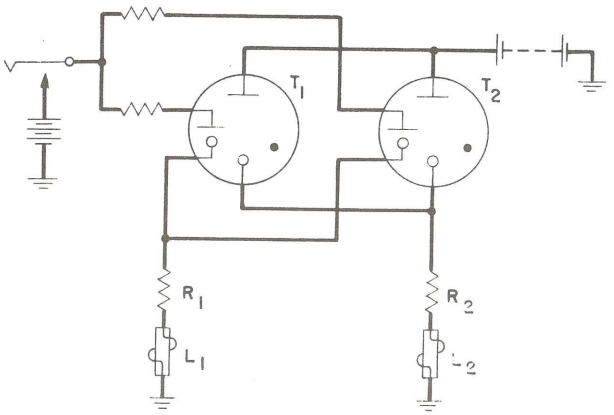


Figure 21-13 A Modification of The Circuit of Figure 21-12

Electron Tubes as Equivalents to Relays

Since an electron tube is either in a conducting or a non-conducting condition, and, hence, acts as a two-valued device, there is a temptation to draw an analogy between tubes and relays. If this analogy is carried too far, however, it will appear that electron tubes are poor substitutes for relays. For example, no present type of tube can replace, without substantial changes in the external circuit, the general-purpose relay with its many possible spring combinations. To make comparisons on this basis alone is not appropriate, since in many applications the characteristics peculiar to electron tubes show them to be particularly suitable as circuit elements, as has been discussed earlier in this chapter.

Nevertheless, it will be useful to illustrate the manner in which electron tubes can be utilized in arrangements equivalent to simple relay circuits. As an illustration, Figure 21-14 shows a relay with its operating and locking paths and the equivalent gas tube arrangement. The relay or tube operates (fires) upon closure of the (ST) key and remains operated until the lead to ground, shown in dotted lines, is opened. The locking property inherent in the gas tube proves to be of advantage in many applications, though means to extinguish the tube must be provided.

Gas tube equivalents to series and parallel makes and breaks are also possible. In Figure 21-15 three tubes (A), (B), and (C) must all be fired to operate tube (D), a condition similar to that of series makes on relays (A), (B), and (C) in the operating path of a relay (D). Here, unidirectional varistor elements (V) (copper oxide, germanium, or selenium rectifier units) are employed in conjunction with the tubes. Units of the germanium type present a resistance of about 50 ohms to small currents in the forward direction (as indicated by the direction of the arrowhead of the symbol) and a reverse resistance of the order of 100,000 ohms.

The utilization of these varistor elements in conjunction with electron tubes is common in electronic switching circuits. Although there are manifold ways

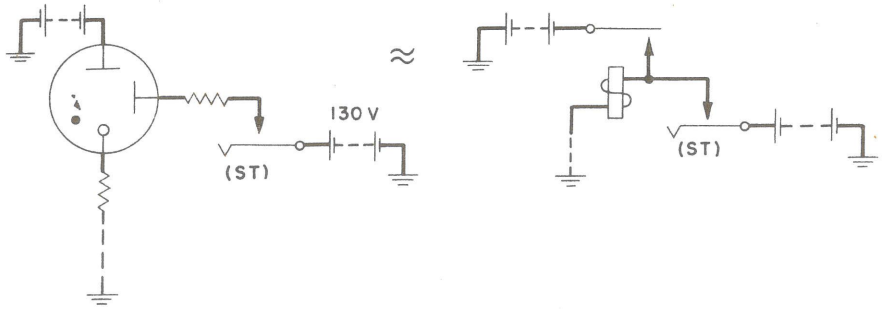


Figure 21-14 Cold-Cathode Gas Tube Operation and Equivalent Relay Arrangement

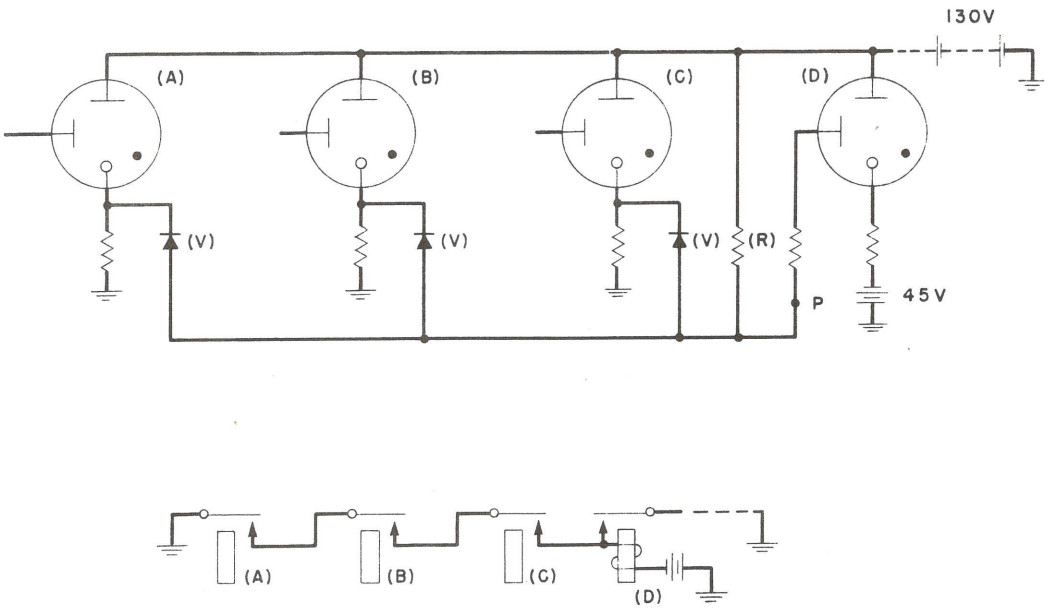


Figure 21-15 Gas Tube Chain and Equivalent Relay Circuit—Series Makes

of interconnecting these elements, only two of these are basic. These two types of connections together with a combination of the two types are illustrated in Figure 21-16. In Figure 21-16A, the potential across resistor R can be more negative than that at any of the three terminals a, b, or c, but not more positive, assuming the resistance of R to be large. That is, the potential of the ungrounded side of R will be that of the least positive (or most negative) terminal. Conversely, in Figure 21-16B, the voltage across R will be that of the most positive (or least negative) terminal. In the combination of Figure 21-16C, voltages measured across the two load resistors, Ra and Rb, will indicate, respectively, the most positive and the most negative potentials present on the terminals. This final circuit can be used conveniently to check for substantially equal potentials since, if all terminals are at the same potential, there will be no voltage difference between points a and a'.

Returning to the diagram of Figure 21-15, point P is on a voltage divider between +130-volt battery and ground. One arm consists of resistance (R) which is high while the other arm consists of three parallel branches each comprising a varistor and the cathode resistor of a gas tube. With the cathode resistors small and the varistors poled as shown, point P will assume a potential nearly equal to the voltage of the least positive cathode. As each tube fires, its cathode voltage rises and when the last of the three tubes fires, point P and the starter anode of tube (D) assume the more positive potential of the cathodes of the control tubes, and therefore, tube (D) fires.

By reversing the polarity of the varistors, an arrangement analogous to parallel make-contacts is obtained, as in Figure 21-17. Point P and the starter anode of tube (D) rise in potential when any one of the control tubes (A), (B), or (C) is fired. Note that although a slightly different biasing arrangement has been used in this example, any of several methods of applying the proper potentials is applicable.

In Figure 21-18 tube (D) will fire when plate voltage is applied to the tube unless any of the tubes (A), (B), or (C) has been ignited previously. If all the control tubes are extinguished, tube (D) will fire as a result of the potential across its starter gap. Here, then, is a circuit equivalent to a control chain of series break-contacts.

If only two tubes in parallel are involved, it is not necessary to

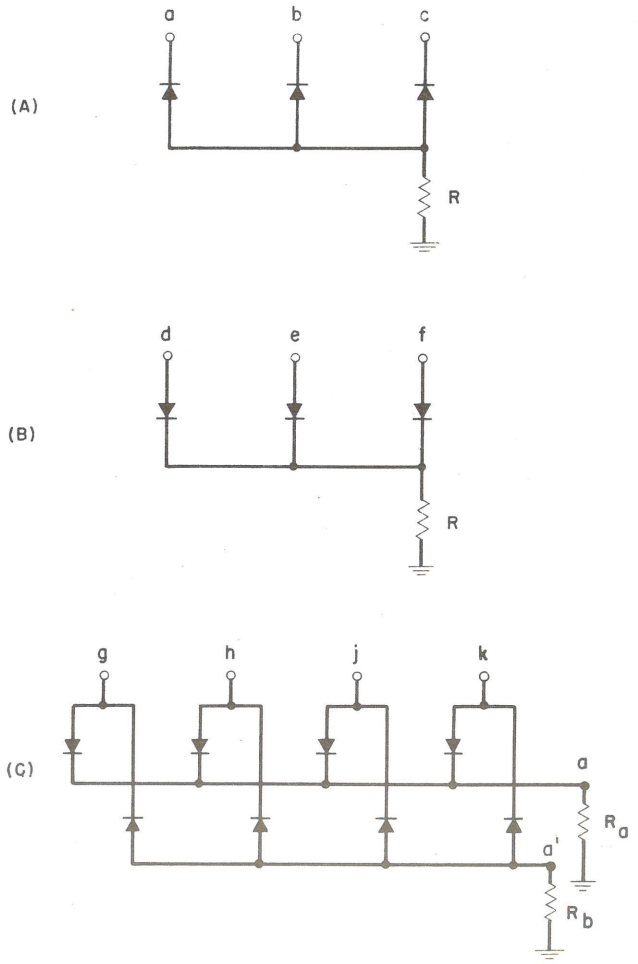


Figure 21-16 Basic Varistor Configurations

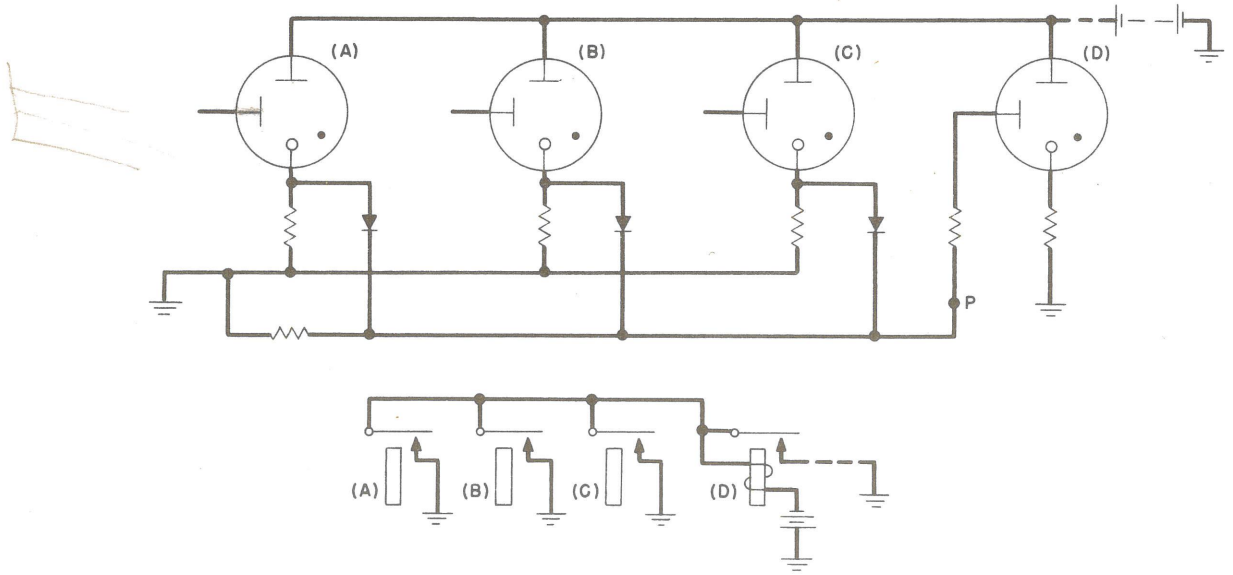


Figure 21-17 Gas Tube Chain and Equivalent Relay Circuit—Parallel Makes

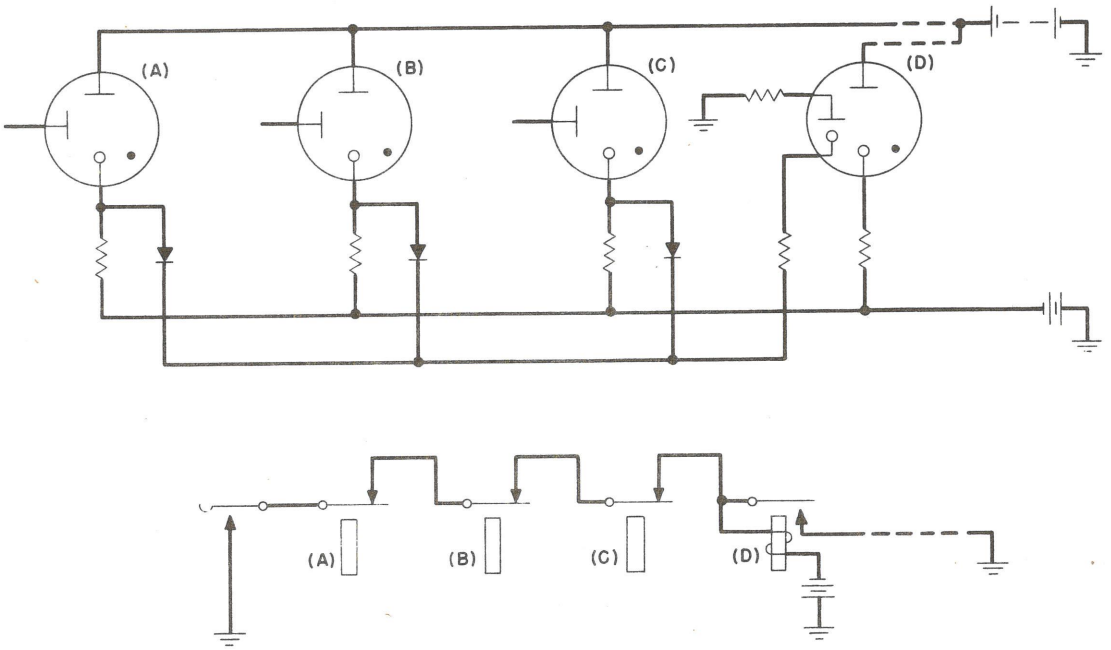


Figure 21-18 Gas Tube Chain and Equivalent Relay Circuit—Series Breaks

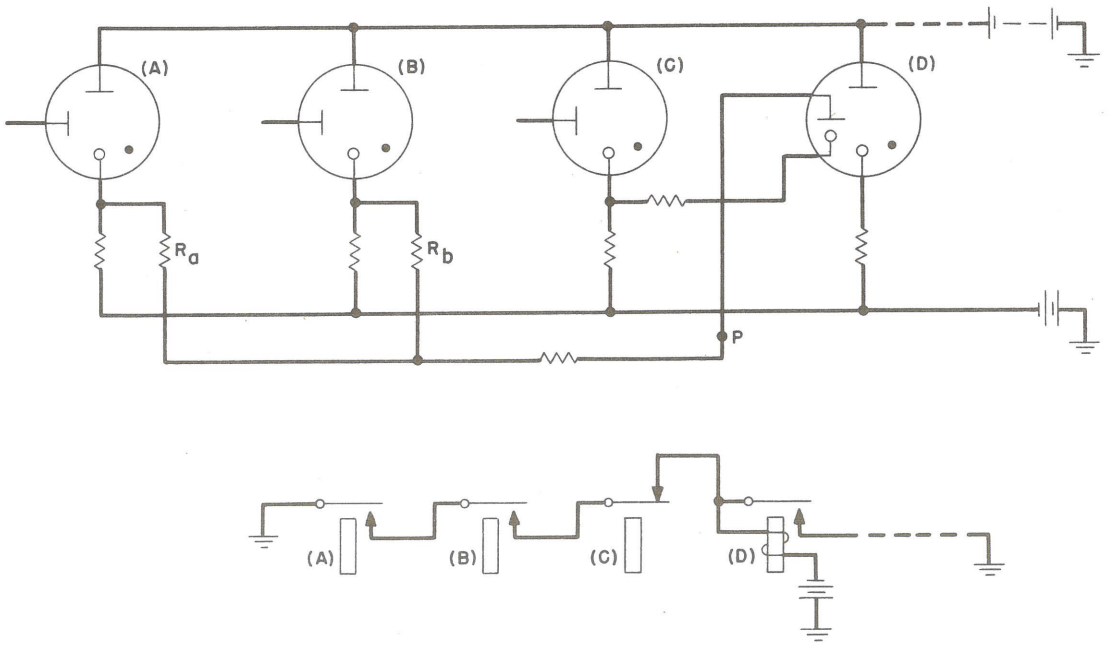


Figure 21-19 Gas Tube Chain and Equivalent Relay Circuit—Series Makes and Breaks

employ varistors to control a third tube as was the case in Figures 21-17 and 21-18. Figure 21-19 shows a circuit in which a tube (D) is fired when tubes (A) and (B) are ignited and (C) is unoperated. Resistors Ra and Rb are adequate to insure that point P will not rise to a potential sufficient to fire the starter gap of tube (D) unless both (A) and (B) are operated. This circuit is equivalent to a relay controlled by a series chain of two makes and a break-contact.

Gas tubes with more numerous elements also may be considered as analogous to relays. The multiple starter anode tube is equivalent to a relay with several operating windings with back-up paths possible between windings. A multiple main anode tube is shown in Figure 21-20 to resemble a relay with make-contacts tied to a common point.

As already mentioned, vacuum tubes in switching applications are usually either conducting or below the cut-off point, the characteristic linearity of grid control being ordinarily of little importance. The cathode follower circuit is employed as a switching device because of its low output impedance, where the self-locking properties of gas tubes would be undesirable. As the grid of the cathode follower is gradually increased in potential from the cut-off value, the plate current also increases gradually. There is no sharp discontinuity between no current flow and current flow sufficient to operate, for example, a relay in the anode-cathode circuit. This is a disadvantage in such arrangements as certain vacuum tube time-delay circuits, in which a relay, in the cathode circuit, is to be operated when a comparatively slowly rising voltage, applied to the grid, reaches a particular value.

In applications where the locking properties of gas tubes are desired but greater releasing speed is also necessary, a vacuum tube arrangement such as the

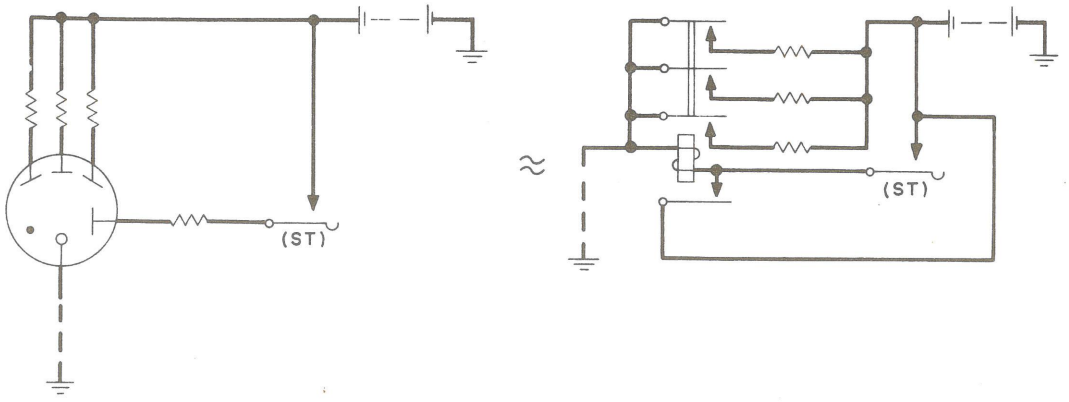


Figure 21-20 Multi-Anode Cold-Cathode Tube

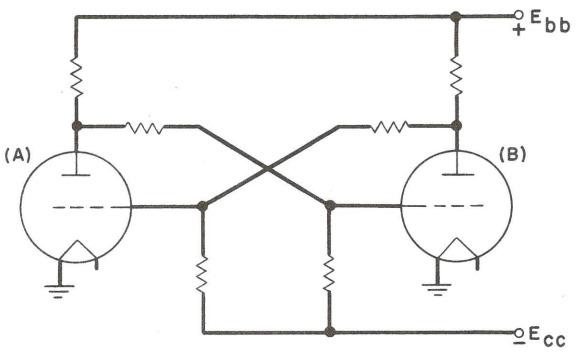


Figure 21-21 The Eccles-Jordan Circuit

Eccles-Jordan circuit, shown in Figure 21-21 can be employed. This circuit has two stable conditions since one and only one tube can be conducting at any time. Thus, the arrangement resembles a locking relay or gas tube circuit, remaining in one stable condition, the normal position, until actuated, and in the second until restored to normal. The input operating signal may be applied to the anode, grid, or cathode of either the normally conducting or non-conducting tube.

Control of Relays

One of the uses for electron tubes in the field of switching arises from the occasional necessity of operating a relay from a high impedance source. Since the relay is, by nature, a current-operated device of relatively low impedance, it is not actuated directly from such a source except in special cases. The electron tube serves as an ideal coupling device for such an application, matching a high impedance input to a low impedance load.

The basic relay control gas tube circuit is shown in Figure 21-22. When the starter anode is supplied with a potential exceeding the breakdown of the starter gap, the tube fires and the relay (K) operates. To release the relay, key (L) must be operated, interrupting the flow of current through tube and relay. A somewhat better arrangement employing a cold-cathode tube, illustrated in Figure 21-23A, provides means for extinguishing the tube after the relay (K) has operated. In this figure, operation of relay (K) places a low resistance (R) in parallel with the tube and in series with (K), reducing the voltage across the tube to below the sustaining value. The disadvantage of this circuit is that the relay is held operated by a current considerably larger than is necessary. Also, unless the condenser and resistor network shown in dotted lines is added, there is the probability that the tube will refire when (L) is opened to release the relay, due to the transient negative voltage kick at the cathode.

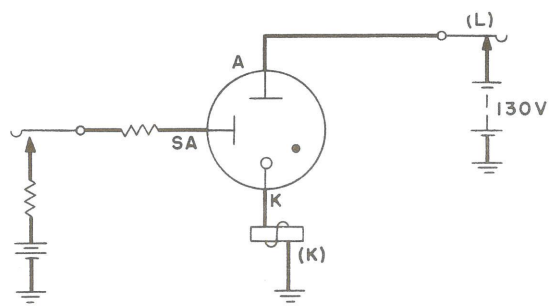


Figure 21-22 Basic Gas Tube Operation of a Relay

A somewhat similar circuit, shown in Figure 21-23B, employs a continuity-transfer contact on relay (K). Operation of relay (K) closes a holding path through key (L) to ground and opens the conducting path of the tube. A

resistance-capacitance network (CP) is again used to avoid reoperating the tube on the release of relay (K).

Vacuum tubes may also be utilized for operating relays from a high impedance input, though the current requirements to operate a particular relay may make the selection of an appropriate tube difficult. On the other hand, the amplification characteristics of a vacuum tube make possible relay operation from a signal of small voltage amplitude. Ordinarily, only the more sensitive types of relays are used directly in conjunction with vacuum tubes. It is often convenient to couple the tube amplifier circuit to a general-purpose relay through a gas tube, thus providing the relay with sufficient operate current.

21.4 ELECTROSTATIC AND MAGNETIC EFFECTS IN ELECTRONIC SWITCHING CIRCUITS

Although it is their characteristic sensitivity and speed of operation that make electron tubes of considerable importance to the switching art, these same characteristics add to the difficulty of designing reliable electron tube circuits. Transient conditions of such short durations and low energy level that their effects on relay circuits are negligible may cause an unprotected tube circuit to operate falsely or to fail to function at all. In the design of tube circuits the designer must anticipate these possible transient conditions and provide the proper protection where necessary. Skillful arrangement of the circuit components, electrically as well as physically, also minimizes the effects of transients.

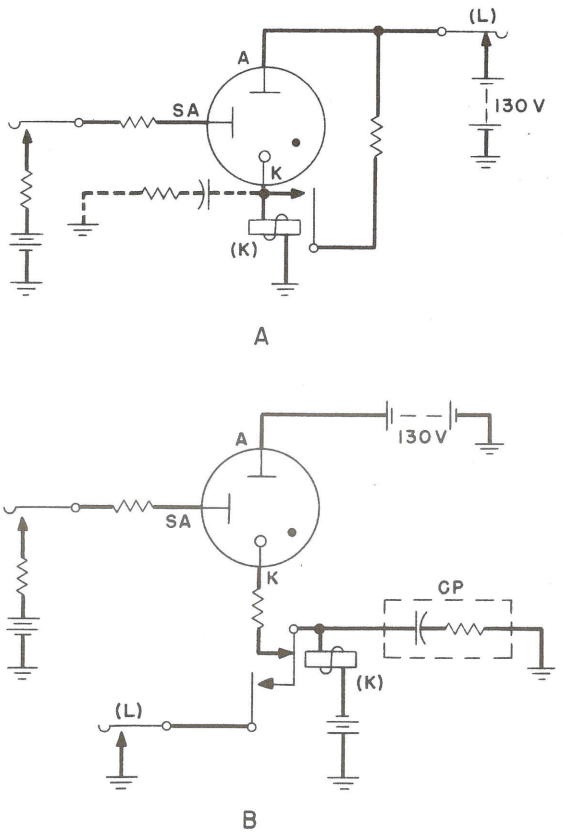


Figure 21-23 Circuits Illustrating Gas Tube Control

Trapped Charges

When the lead to an electrode of a gas tube is opened, for example, to extinguish the tube, the electrode tends to become charged as a result of electrostatic coupling and leakage between the electrode lead and other circuit elements. If the electrode is electrically floating, with respect to ground and the rest of the circuit, the charge will be trapped on the electrode. Depending upon the magnitude and polarity of the charge, the tube may fire falsely or refuse to fire on the next usage of the circuit.

There are two solutions to the problem of trapped charges: (a) prevention or reduction of the accumulation of the charge; or (b) rapid dissipation of the

charge after it has accumulated. Various schemes of accomplishing (a) involving the addition of condensers between various electrodes and ground have been proposed. However, in most cases the economical solution, at present, is to drain trapped charges from the cathode of the tube by a 10-megohm resistance connected between the cathode of the tube and ground. With the cathode at ground potential under standby conditions, due to the 10-megohm resistance, a trapped positive charge of sufficient potential on the starter anode will ionize the starter gap and the charge will fall below the sustaining voltage value for the starter gap. Conduction through the main gap cannot be sustained with the gap in series with 10 megohms resistance.

Surge Conditions

High speed, transient surges of potential which may affect electron tube circuits may appear on battery and ground leads as a consequence of coupling between these leads and those of other circuits. Also, magnetic coupling between relays in the electron tube circuits and external, closely adjacent relays, may result in transient conditions on those tube electrodes which are connected to relay windings.

Transients appearing on battery and ground leads may be by-passed around the tube circuit by connecting a 0.001 microfarad condenser between battery and ground as electrically close to the circuit to be protected as possible. Surge conditions resulting from transformer action between relays in the circuit and those external to the circuit may be minimized by proper physical placement of the circuit relays. In practical circuits it is also well to allow ample operating voltage margins. Voltage surges produced by opening relay contacts in series with relay windings may be reduced by placing a resistance-capacitance network across such contacts.

Conclusion

This chapter has discussed only elementary electronic switching circuits. In succeeding courses on functional switching circuits, examples will be given of the design techniques of complete switching circuits using electronic tubes exclusively, or combinations of relays and tubes.

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