Mr Gill. [illegible]

ELECTRICAL COMMUNICATION

Technical Journal of the
International Telephone and Telegraph Corporation
and Associate Companies

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INTERNATIONAL TELEPHONE AND TELEGRAPH

Volume 28 DECEMBER, 1951 Number 4

ELECTRICAL COMMUNICATION

Technical Journal of the
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
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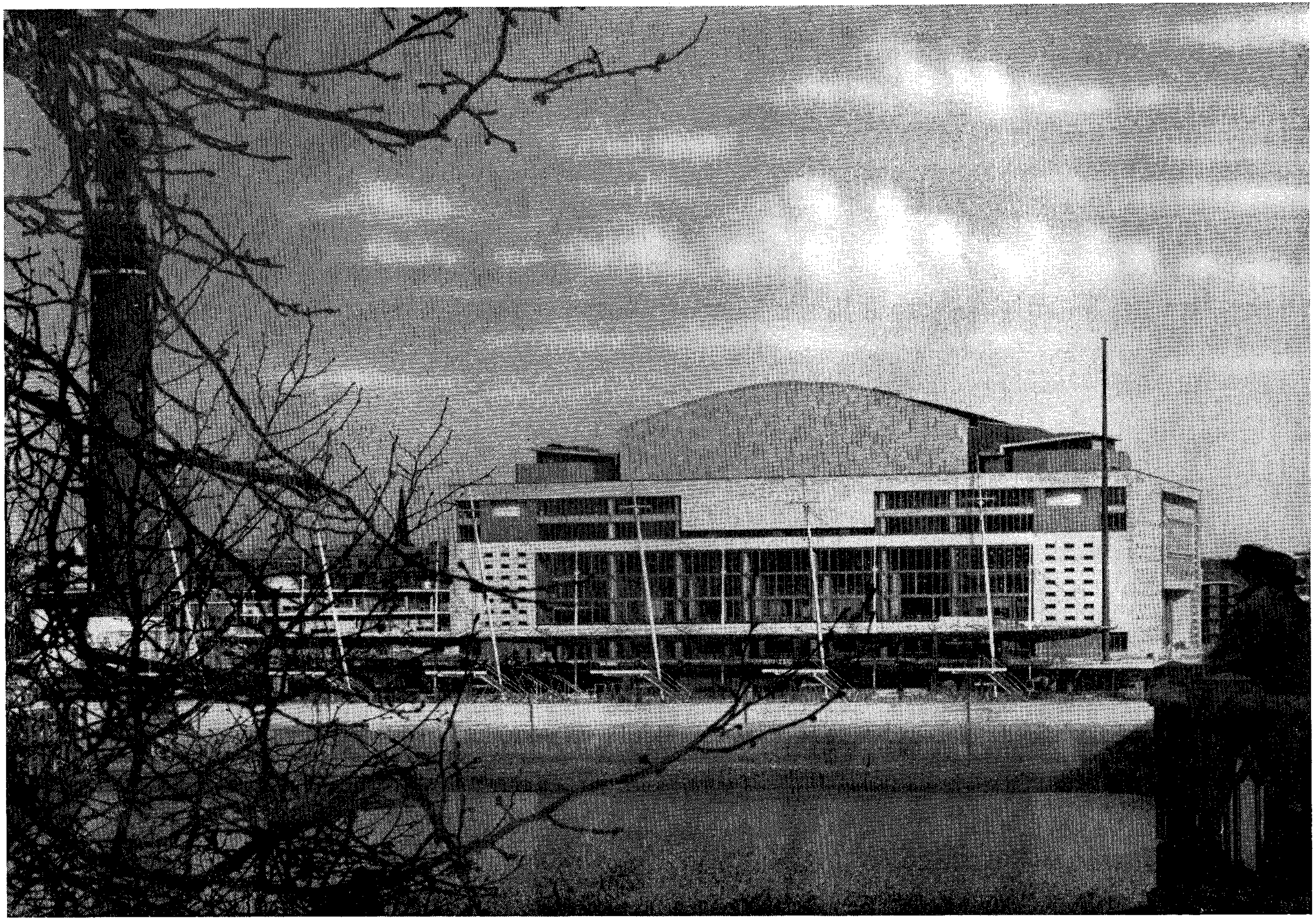


By courtesy of the "Architectural Review," London, England.

Royal Festival Hall as seen from Victoria Embankment. Recently completed for the Festival of Britain, it is the first of a group of structures that will be part of the permanent development on the South Bank of the Thames, in London. This large concert hall is flanked on the left by an old shot tower.

Sound Reinforcement and Production For Royal Festival Hall

By J. L. GOODWIN

Standard Telephones and Cables, Limited; London, England

ROYAL Festival Hall, the newly completed London County Council concert hall, stands amongst the temporary pavilions of the Festival of Britain South Bank Exhibition; later it will form part of the scheme of the London County Council for permanent development in that area.

The proximity of the building site to a main railway viaduct had a great influence on the design, as it was essential to exclude any trace of external noise. From an acoustic point of view, the arrangement of accommodation was similar to that of broadcasting studio buildings, and in this case the auditorium became the central sound-proofed structure. The auditorium is raised some 30 feet above ground level; beneath it are the main foyer, restaurants, and ancillary accommodations.

The envelope outside the double air-spaced wall of the auditorium contains all the remaining accommodations necessary to the working of the concert hall. These rooms and areas enjoy views across the river and the surrounding site and at the same time serve as buffers against external noises. Some of the areas immediately adjacent to the auditorium doorways have been given special acoustic treatment to ensure that noise is rapidly absorbed without making conversational conditions too unreal.

The design and treatment has resulted in a large attenuation so that when one is seated in an absolutely quiet auditorium no external noises can be heard.

Parallel-sided walls were chosen for the auditorium in preference to the more usual divergent form, and a vertical section approximating to an ovoid shape can be seen in Figure 1.

1. *Loudspeaker Placement*

The sound reinforcement presented some difficult problems inasmuch as a concert hall has no proscenium arch and therefore no ideal site for loudspeakers. Its acoustic properties were to be perfect for concerts but were not ideal for our job. Aesthetic conditions also had to be satisfied, and whilst the ideal loudspeaker site might have been chosen on technical grounds, this was invariably found to disagree with the general architectural lines.

In any auditorium where a high-level system of reinforcement is employed, it is desirable from the point of view of realism to have the loudspeakers as near to the human speaker as possible, a condition which is always adverse to the requirements of a good feedback margin. The construction of the Royal Festival Hall did not permit the selection of loudspeaker sites abreast of the microphone, nor could a site well to the rear of the platform be used because of feedback considerations.

The reflecting canopy above the orchestra platform appeared to be a possible site and after a study of the various angles of the sections, the front leaf was chosen as the position most likely to cover the whole auditorium.

During the construction of the building, the original position of this canopy was moved and the whole structure was lifted several feet, which meant that the loudspeakers would be unlikely to cover the last six rows of the terrace stalls. Speech tests were carried out during the hall-tuning period, and it was found necessary to supplement the main bank of loudspeakers with two directional units in the podium slot behind the choir assembly area of the platform. By controlling the level of these units, the feedback margin was not impaired, and a useful degree of reinforcement was obtained in the shadowed area.

Recently, work has been carried out under the Department of Scientific and Industrial Research both in Britain and in Germany on the effect of time delays in speech reinforcement systems.[1] It has been shown[2] that improved realism results if the high-level speakers can have a delay of 5 to 35 milliseconds introduced into frequencies where the wavelength is comparable to the width of the slot. In the case of these loudspeakers, that figure is 8000 cycles per second

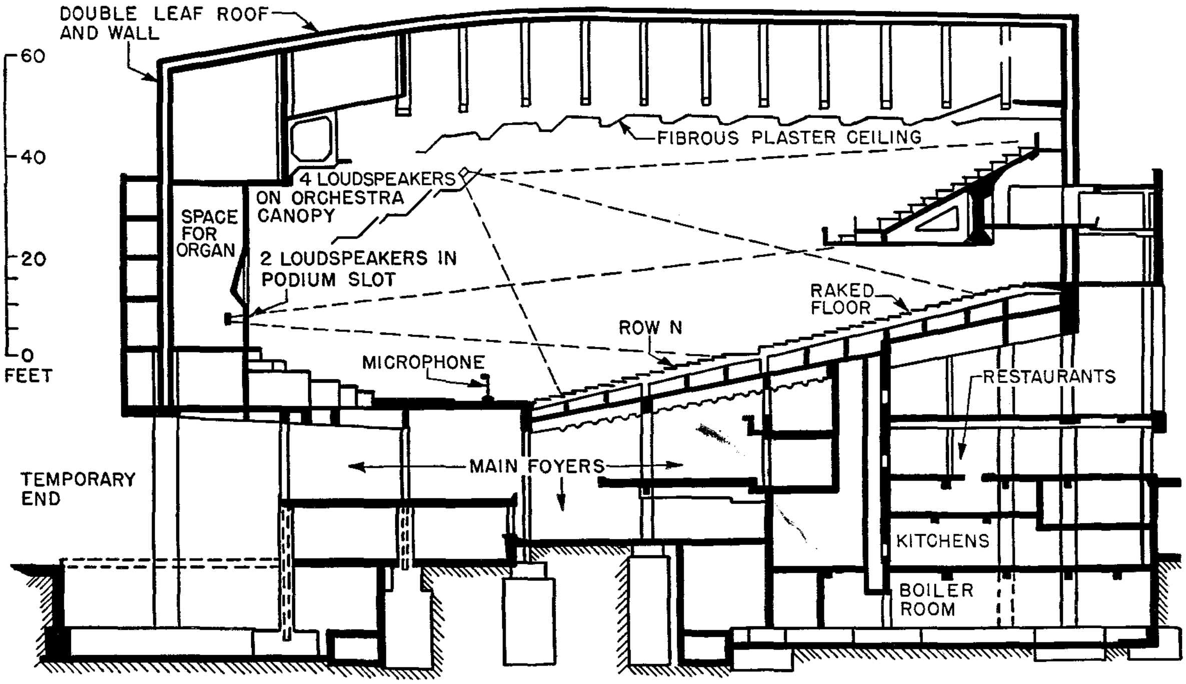


Figure 1—Section of auditorium through centre line showing relative locations of microphone and loudspeakers.

their circuit to ensure that the unaided voice is heard first. From Figure 1, it is seen that this condition prevails over a large part of the auditorium seating: as an example, row *N* in the stalls would be subject to a delay of 15 milliseconds.

An effort has been made to diffuse the sound as much as possible, and in that direction a bank of four 12-inch-diameter cone loudspeakers has been employed, each of which radiates its energy through a slot $10\frac{1}{2}$ inches by $1\frac{1}{2}$ inches (27 by 4 centimetres). This arrangement is employed wherever diffusion of the upper frequencies is required. The presence of the slot avoids the usual focussing of the higher frequencies along the loudspeaker axis, and is effective up to and an almost uniform spread of the higher frequencies is obtained up to an angle of 75 degrees each side of the axis.

This diffusion undoubtedly assists the feedback margin under certain conditions, as the loudspeaker response tends to be less "peaky" with this device, and there is less chance of a focussed higher frequency being reflected back into the field of the microphone.

Type *4033A* cardioid microphones, having a back-to-front ratio of 20 decibels over the major part of the characteristic, have been employed throughout this installation. The use of such microphones in "live" auditoria materially assists in obtaining a better feedback margin, which is an important consideration when a reasonable level of reinforcement is required without giving the system a tendency towards acoustic instability.

Figure 2 shows a view of the auditorium looking towards the platform from the grand tier. Seven loudspeaker slots will be seen in the

[1] H. Hass and E. Meyer, "Influence of a Single Echo on the Audibility of Speech." Translation of a German paper published by Building Research Station, Watford, England, under Library Circular 363.

[2] P. H. Parkin and W. E. Scholes, "Recent Developments in Speech Reinforcement Systems," *Wireless World*, v. 57, pp. 44–50; February, 1951.

photograph; every alternate one is used, so that there are two loudspeakers in operation on each side of the centre slot.

2. *Reinforcement System*

A simplified block diagram of the reinforcement system is given in Figure 3, and from the general arrangement it will be seen that, fundamentally, the system is two-channel stereophonic, with provision for use in the more usual mon-aural arrangement. There have been great advances in the improvement of quality of reproduction in the past ten years and several papers have been written on stereophony.[3–6] It therefore seemed desirable that if this hall were ever to be used for any amount of relay work or for the reinforcement of certain musical instruments, a bin-aural system should be provided to give the best realism consistent with cost.

It was considered that the provision of twelve microphone faders would be likely to meet most requirements but there needed to be many more than that number of auditorium microphone circuits and other incoming low-level programme sources. It was decided to bring up all inputs on standard Post Office jacks, and to plug the fader channels into them as required. Each fader was therefore terminated in a plug on an extendible cord, whose available length was controlled in the conventional telephone switchboard manner by the use of pulleys and cord weights.

The 50-ohm ladder-network faders have a total attenuation of 52 decibels in steps of 1 decibel over the main part but are graded towards the high-attenuation end. These are series

[3] J. Moir, "Stereophonic Sound," *Wireless World*, v. 57, pp. 84–87; March, 1951.

[4] K. de Boer, "A Remarkable Phenomenon with Stereophonic Sound Reproduction," *Philips Technical Review*, v. 9, pp. 8–13; January, 1947.

[5] K. de Boer, "Formation of Stereophonic Images," *Philips Technical Review*, v. 8, pp. 51–56; February, 1946.

[6] "Symposium of Wire Transmission of Symphonic Music and Its Reproduction in Auditory Perspective" (6 papers), *Bell System Technical Journal*, v. 13, pp. 239–308; April, 1934.

Figure 2—The auditorium as seen from the grand tier. Cone loudspeakers are mounted behind four of the seven slots in the reflecting canopy above the orchestral stage.

By courtesy of the "Architectural Review," London, England.

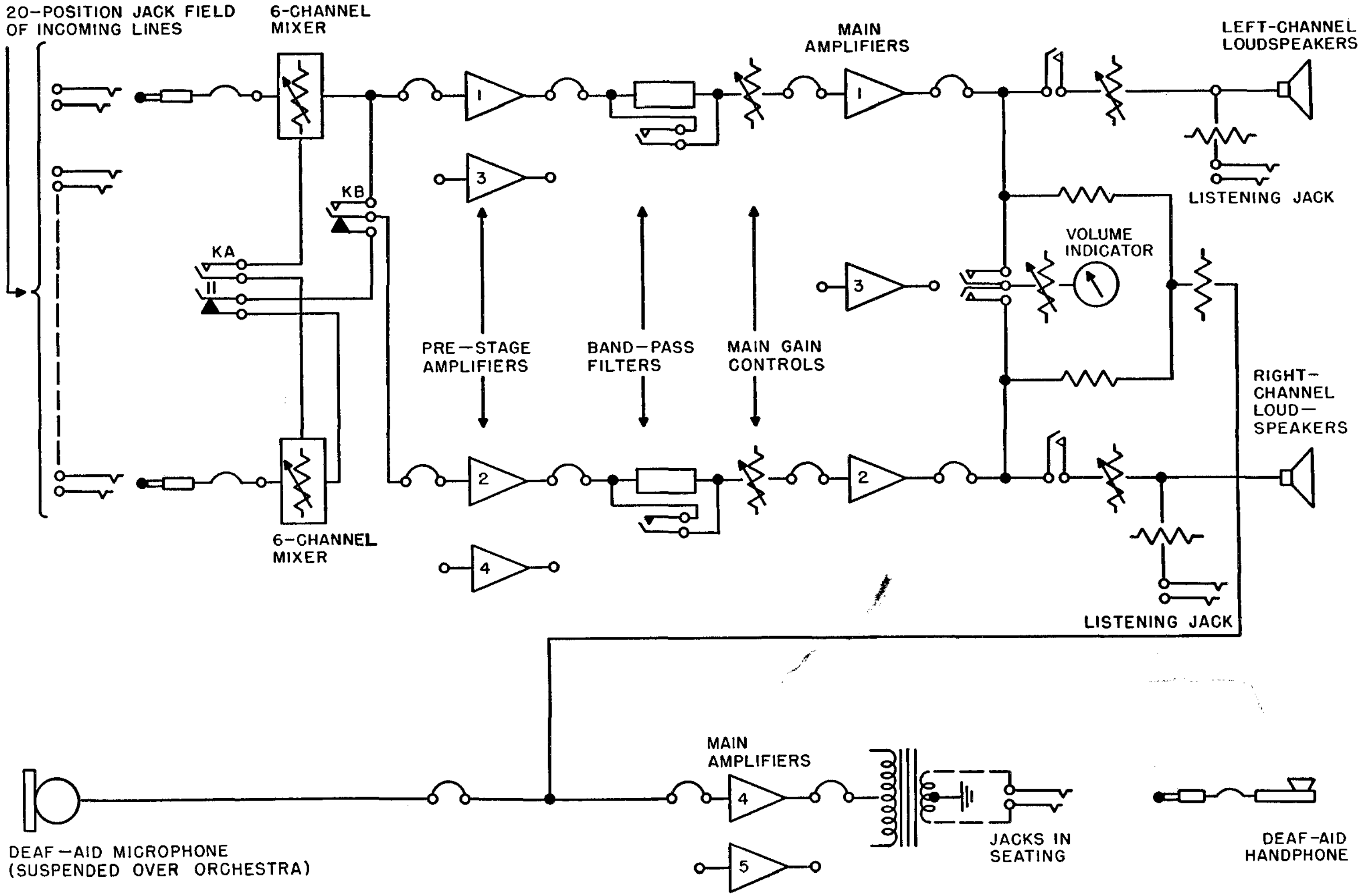


Figure 3—Block schematic diagram of the system.

connected to form two 6-channel mixers normally feeding the 30-decibel pre-stage amplifiers *1* and *2*. By operating key *KA*, the mixers are conected in series to form a 12-channel mixer into pre-stage amplifier *1* only.

The operation of key *KB* feeds the left-channel mixer into the inputs of the pre-stage amplifiers connected in parallel and is the more usual method of operating this system.

The pre-stage amplifiers are followed by an equaliser for speech and a main gain control and serve to take care of the mixer, equalisation, and main-gain-control losses. The equalisation provided is a band-pass filter having the characteristic shown in Figure 4.

The signal now passes on to the main amplifiers giving 120 decibels gain, where the level is raised to a suitable value for loudspeaker distribution.

Each amplifier in the system has its terminations brought up to U-link panels so that direct access into the amplifier, the sending, or the receiving circuit can be made from the front of the equipment rack.

A further and important use of the U-link system allows the immediate replacement of an amplifier by using patching cords and making two cross connections on the panel face. It will be seen from Figure 3 that a common spare has been provided for the main amplifiers, whilst each pre-stage amplifier has its own spare. The reason for this is physical rather than electrical, as each pre-stage amplifier panel mounts two separate amplifier channels, which are supplied from a common power pack. It is therefore convenient for a pair of working channels *1* and *3* to be on one panel with the spares *2* and *4* on the other.

The output circuits are quite straightforward, and it will be seen that a volume indicator[7] can be switched across either output. This is not only useful as a visual monitoring device on auditorium volume, but serves as an absolute check on the level being fed to the deaf-aid amplifier. This feed is made through high resistances from each side so that the channel separation is not upset and in the event of one channel becoming non-operative there would be a 6-decibel change in level, which, though noticeable, is not likely to impair the service to the audience. A secondary source for the deaf-aid

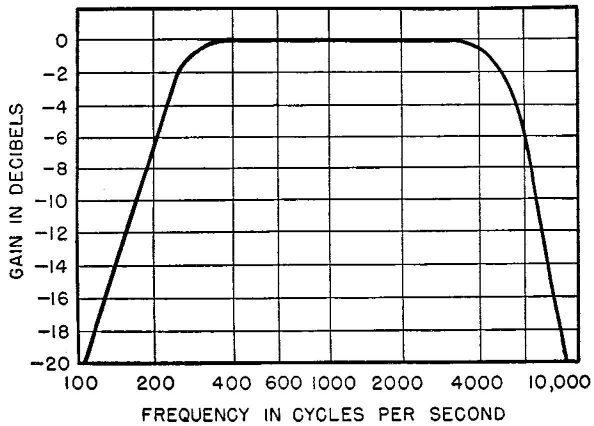


Figure 4—Gain frequency characteristic of the band-pass filters used for equalisation on speech only.

system is provided from a separate roof microphone, and it is a signal from this that is used during a concert when the reinforcement system is not in operation.

Each outgoing channel is split into five circuits, all of which are controlled by individual key switches, and three of which have bridged-T line attenuators. One of the latter feeds the two loudspeakers mounted each side of the orchestra canopy centre line mentioned above, and shown in Figure 2. The bridged-T attenuators are simply constructed on an "Oak" switch framework, and are designed with a total attenuation of 25 decibels in 10 steps of 2.5 decibels each. Such an arrangement ensures that the amplifier is always faced with the same load, irrespective of the control settings.

As each line leaves the console, it is bridged with a jack that permits an operator or maintenance engineer to make aural headphone tests on any outgoing line. The other lines not mentioned in detail above are spare outlets that would generally be used for feeding loudspeakers for over-flow audiences outside the main auditorium.

Successful operation and use of a sound reinforcement system in an auditorium depends on the operator being able to hear the reinforced sound himself, instead of relying on a local monitor loudspeaker. The equipment is therefore physically divided into two parts, an operator's

[7] H. A. Chinn, D. K. Gannett, and R. M. Morris, "A New Standard Volume Indicator and Reference Level," *Bell System Technical Journal*, v. 19, pp. 94–137; January, 1940: *Proceedings of the IRE*, v. 28, pp. 1–16; January, 1940.

control console within the auditorium and the apparatus racks mounted in the central sound-control room.

3. *Control Console*

The control console is located in a small cubicle, mid-way up one side of the auditorium; the shape of the cubicle largely governed the dimensional design of the console. As is usual in auditoria, all possible space is taken up for seating. It is seldom possible for a sound console to use up seating area, and in the Royal Festival Hall a position adjacent to the terrace stalls and with a full platform view was found. This cubicle is 6 by 3 by 8 feet high (1.8 by 0.9 by 2.4 metres) and is provided with a raised floor on which to mount the console, so giving the operator an unobstructed view above the heads of the audience. After allowing for door space, there was left a space 4 by 3 feet (1.2 by 0.9 metres) in which to house a console and operator together with ancillary equipment such as a clock, two telephones, and cue-lights control. These physical considerations, coupled with the dual-channel nature of the electrical circuit, lead to the rather unusual design of the console shown in Figure 5.

The general shape resembles that of a miniature upright piano and along the narrow sloping front are arranged the 12 faders of the left and right 6-channel mixers. The keys at the centre are *KA* and *KB* used for switching between mon-aural and bin-aural operation.

This arrangement allows an operator seated at normal chair height to have these controls right at his fingertips, whilst a short movement allows him to reach a fader plug that is either in the static position or plugged into one of the incoming-line jacks.

The larger, and nearly upright, panel carries most of the high-level equipment, although the lower central portion of it is screened to accommodate the 28 incoming-line jacks. To each side of this jack field, and fitted with large "shadow" type fader dials, are the main gain controls in each channel, having a total attenuation of 50 decibels in 180 degrees of rotation. This type of dial shows all black at maximum attenuation and a complete white hemisphere for zero attenuation. In Figure 5 these controls can be seen partially rotated. This arrangement gives an operator an immediate picture of the state of the main channels.

A volume indicator is mounted centrally and, with its associated sensitivity control and selector switch, can meter either of the two channels.

The top left- and right-hand sides of this panel are completed with the loudspeaker-circuit controls mentioned above. The general arrangement, therefore, gives a layout where the operational controls are at the fingertips and the pre-set controls are not quite so accessible. On the reverse side, the maintenance engineer is presented with apparatus that is easily reached by removing the rear panel, which in turn forms

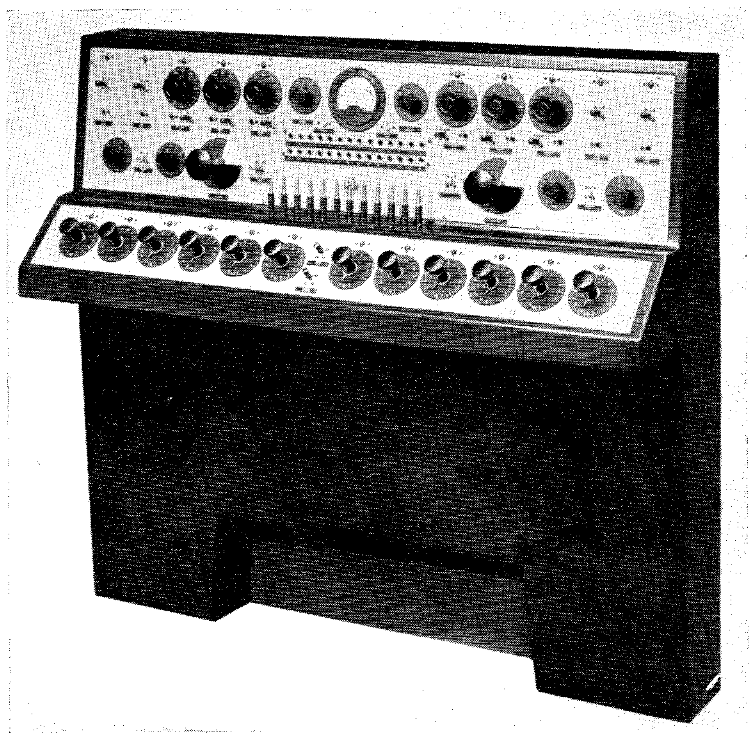


Figure 5—Control console is located in a cubicle in the auditorium.

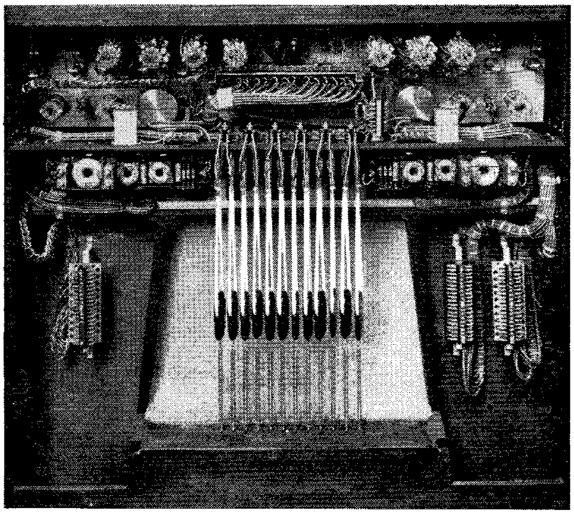


Figure 6—Rear view of console.

a portion of the auditorium panelling of the sound-control cubicle.

The rear view of the console in Figure 6 shows the 12 cord weights aided with springs, which proved to be necessary as the screened cordage used passes two acute bends on its way from the console face.

4. Deaf-Aid System

Approximately 15 per cent of the seating has been equipped with sockets into which deaf-aid handphones can be plugged. The sockets are standard *B*-gauge telephone jacks, and a pair is mounted on a small plate let into the armrest that separates two adjacent seats. The sockets are fed from a deaf-aid amplifier, which is housed in the main rack framework and, as has been mentioned above, receives its signal from the main channels.

5. Announcing System

A building as large as the Royal Festival Hall has also to be provided with an overall announcing system that can accept inputs from strategic positions and can broadcast an announcement to one or a number of loudspeaker groups. In addition to microphone inputs, this system can accept a signal from two gramophone pick-ups or from an external line.

The elements of this system are outlined in the block diagram shown in Figure 7, and it will be seen that the amplifiers are able to accept an input from the 4-channel mixer or from the interval-tone generator. This latter device takes the place of the more usual bells that are sounded in the refreshment rooms, bars, and foyers at the close of the interval period.

We were asked to radiate the note *A* (440 cycles per second) and it was thought that the note from a struck bar would not only be true, but would also produce a fairly rich tone as compared with a note from a tuning fork. This was therefore adopted as the source, and the bar is struck with a motor-actuated hammer and the

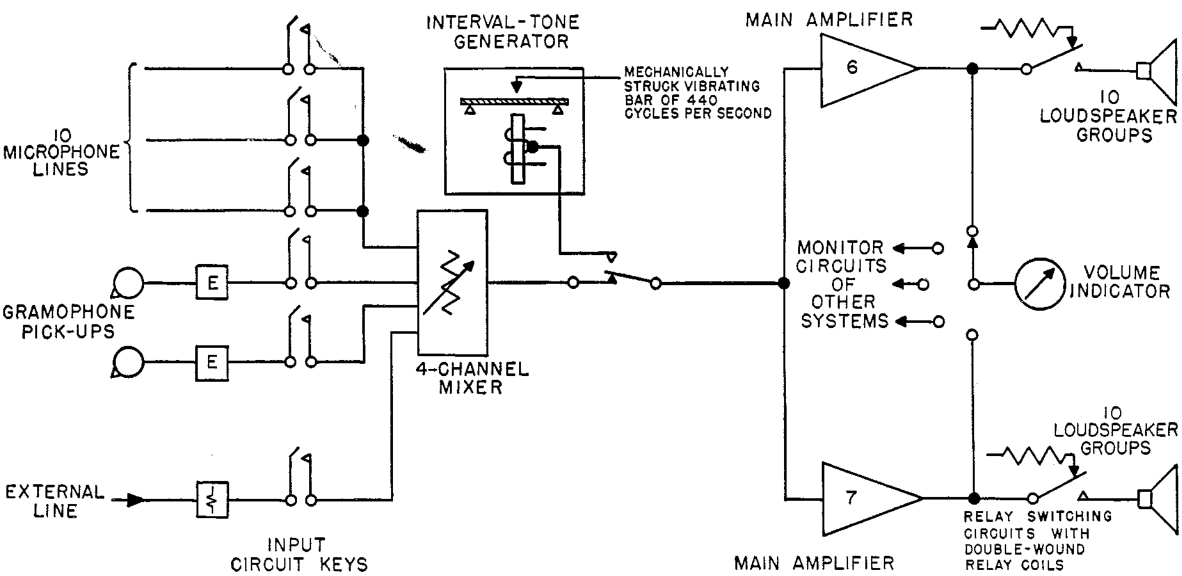


Figure 7—Block schematic diagram of the central-announcing and interval-tone system.

vibrations converted into electrical energy by a small coil and magnet system mounted beneath the centre of the bar. A number of teething troubles were overcome and eventually a pleasing, and yet arresting, note was produced over the loudspeakers.

The control of this system, apart from switching on the amplifiers, had to be remote and under the care of the concert steward. The loudspeaker relay coils are provided with two windings, and the key circuits are arranged so that when the steward operates the interval-tone key, he radiates the note to all loudspeaker groups except those that have been previously cancelled by the keys on the control-desk panel. The double-wound relay coil is wired in association with a three-position key. In the normal position, the winding is in circuit and ready to receive polarising voltage from the steward. In the "up" position, this winding is out of circuit, thus cancelling the "master" operation; whilst individual control is afforded by operating the key downwards.

The control of this central announcing system is made from the desk situated in the sound-control room and illustrated in Figure 8. The keys in the upper row controlling the loudspeaker group relays are shown in the pre-set position ready for the interval-note broadcast. The right-hand desk corner is shown open to expose a well into which a gramophone reproducer may be fitted. The desk "corner" is stowed in a vertical position at the side without impairing the general styling of the desk.

The centrally mounted volume indicator has its channel-selector switch coupled to the monitor loudspeaker in the control room, thus allowing a visual and aural check on the programme level. This meter circuit can be bridged across any of the outputs of the various systems so that an engineer has monitoring facilities on any desired channel.

Headphone monitoring of the deaf-aid system can be made from one of the sockets in the front edge of the desk, the remaining five being provided for additional monitoring that might be required if a simultaneous speech interpretation system is installed for a multi-language conference in the auditorium.

Communication to all parts of the hall is provided by an automatic house telephone, and to the auditorium console by a direct-line central-battery-operated telephone.

The concert hall steward also has direct access to the control engineer over an extension of his specially designed loudspeaking telephone with the transducer unit built into the desk top and radiating through the slot below the control panel.

6. *Acknowledgment*

Acknowledgments are made to the London County Council, Chief Engineer's Department, and to the Director, Building Research Station, for their assistance in the planning and installation of the equipment.

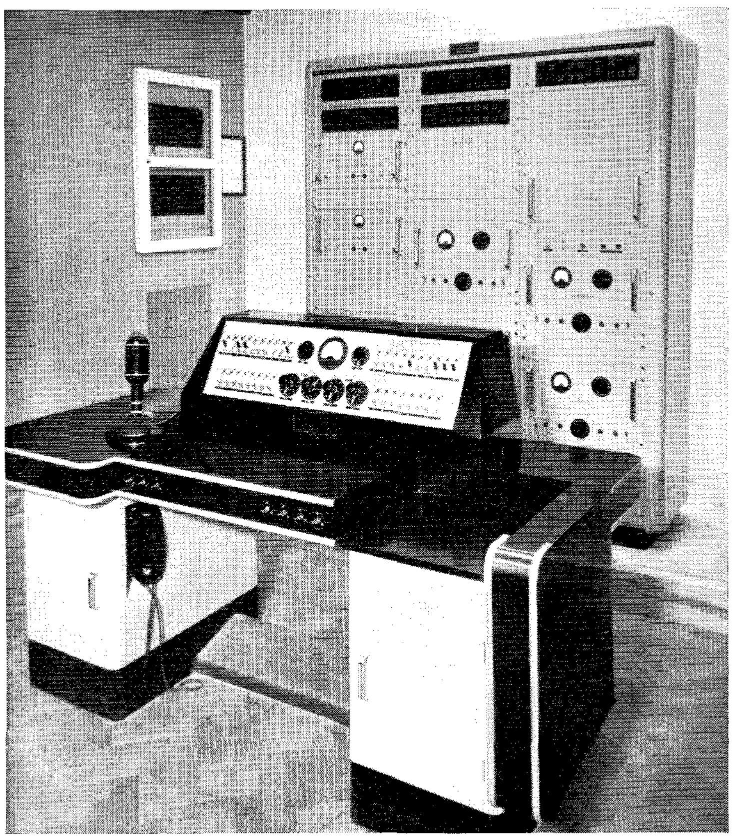
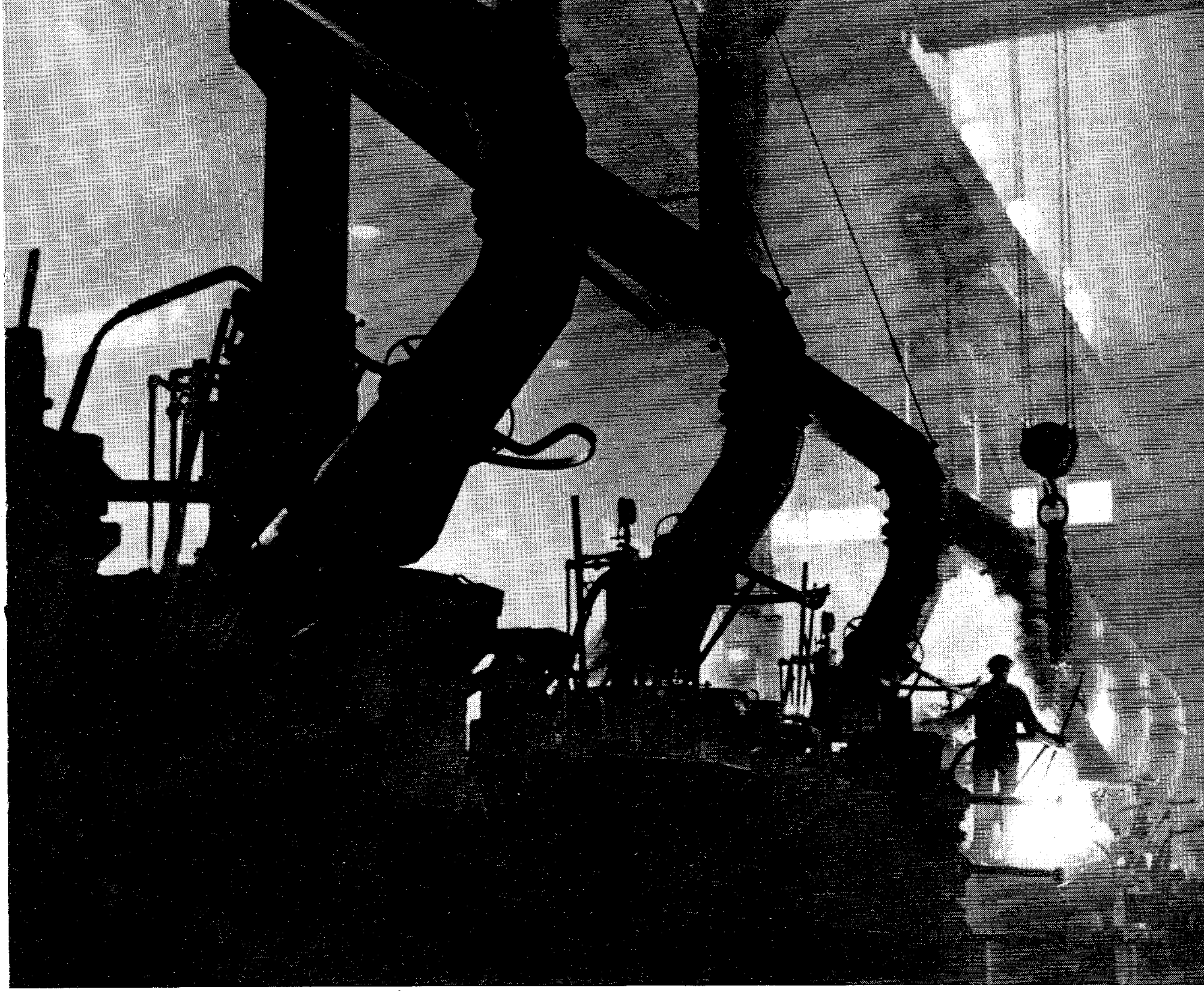


Figure 8—The control desk for the central-announcing system. The main equipment racks are in the back-ground.

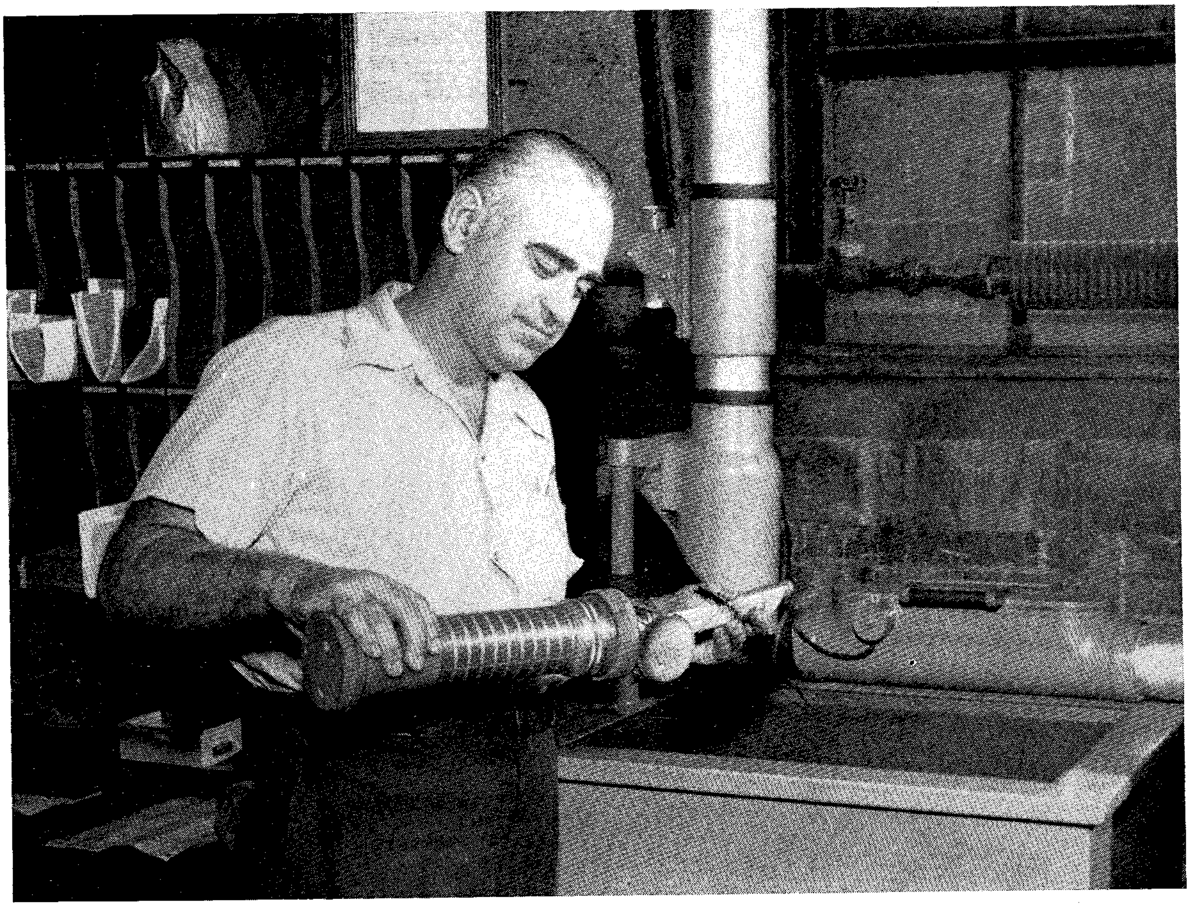


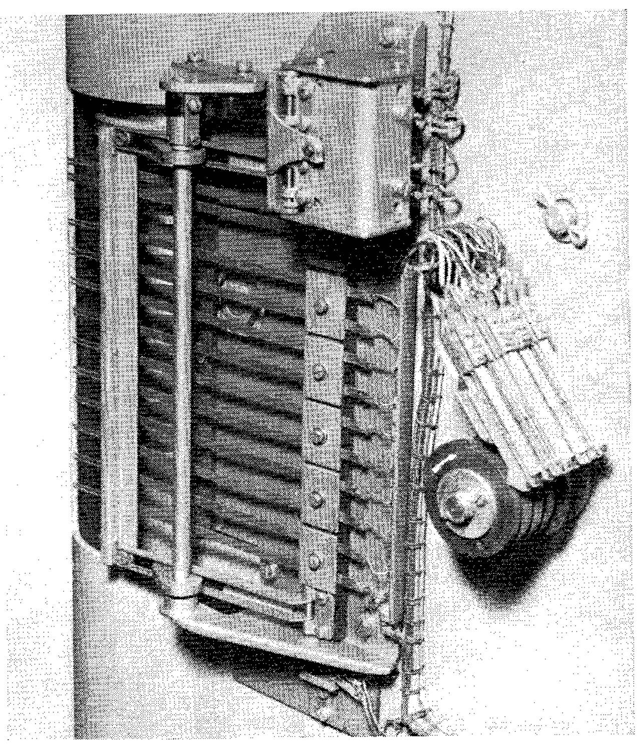
In the casting shop.

Automatic Selective Pneumatic Tube System Installed at the Bridgeport Brass Company

IN 85 YEARS, the Bridgeport Brass Company, of Bridgeport, Connecticut, has amassed an impressive record in the introduction of "firsts" in its industry. This corporation, one of the largest fabricators and suppliers of brass products and similar alloys in the country, developed the micrometer caliper for close measurements, it pioneered in the adaptation of the electric furnace to casting processes, it manufactured the wire for the first long-distance telephone line in America, and supplied vastly improved boiler tubes for the battleships of the Spanish-American war; and during the following world wars was one of the vital producers of cartridge cases, condenser tubes, sheet brass, wire, and tubing.

In addition to the two plants in Bridgeport, the company also operates plants in Indiana, New Hampshire, and in Montreal, Canada. The fabrication of brass is a "heavy" industry, requiring large machinery and wide areas. To check constantly on the movement of orders through this plant and maintain laboratory control of the product, required many messengers.

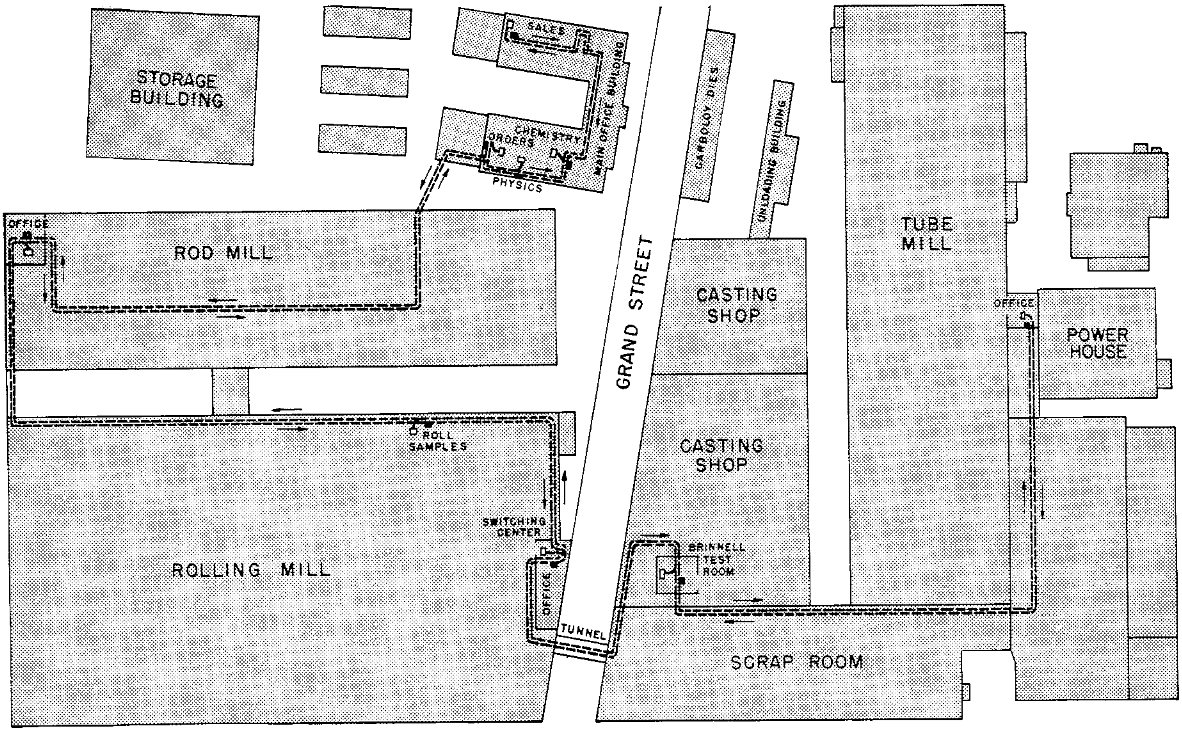




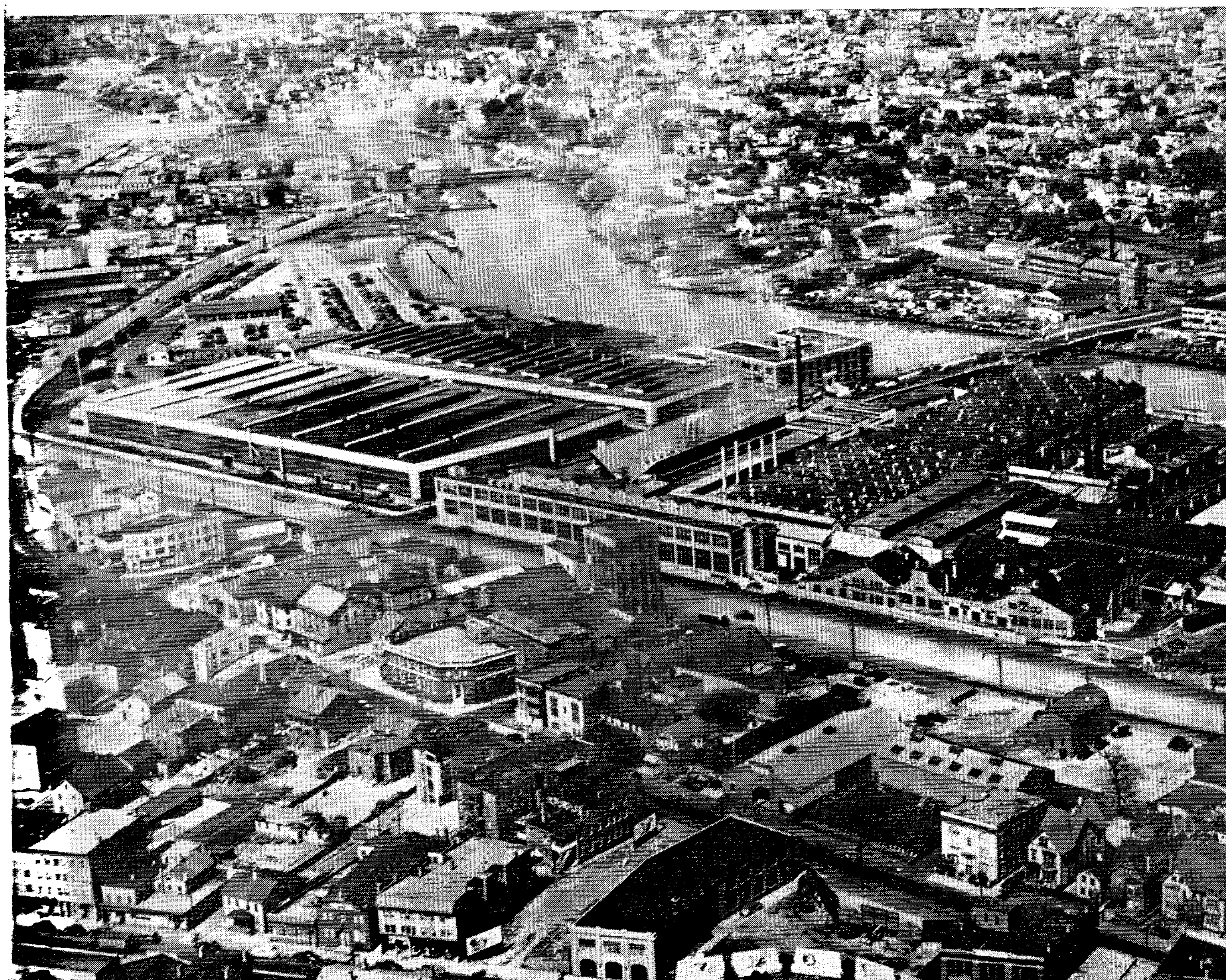
Above is a photograph of the station at the rolling-mill office. The vertical tube is an offshoot of the "return" tube through which carriers are delivered to the station. When the man has inserted the sample in the carrier, he will dial the number of the desired station on the rings of the carrier and place it in the horizontal "go" tube just above the box.

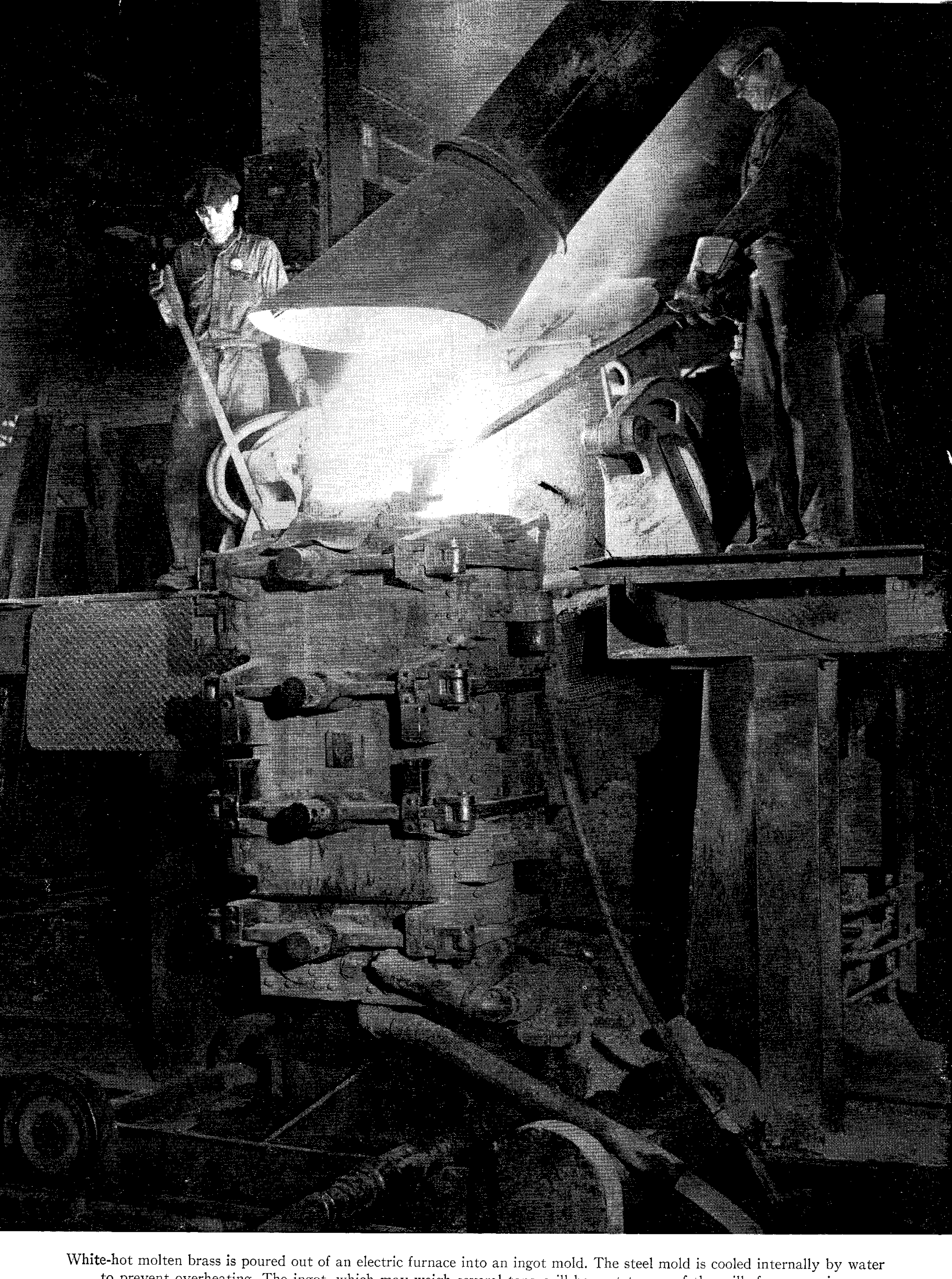
At the left are the feelers of the central switching device. The carrier is stopped here momentarily while these fingers contact the ten stationary rings and the two dial rings on the carrier to "read" the address of the station of destination.

On the opposite page is an aerial view of the Housatonic plant of the Bridgeport Brass Company where the pneumatic-tube system is installed. Above it is a drawing of those buildings of the plant through which the tubes run. The horizontal dimension of the drawing represents a distance of about 1125 feet (340 meters). The dashed lines represent the two loops that pass through 9 stations.

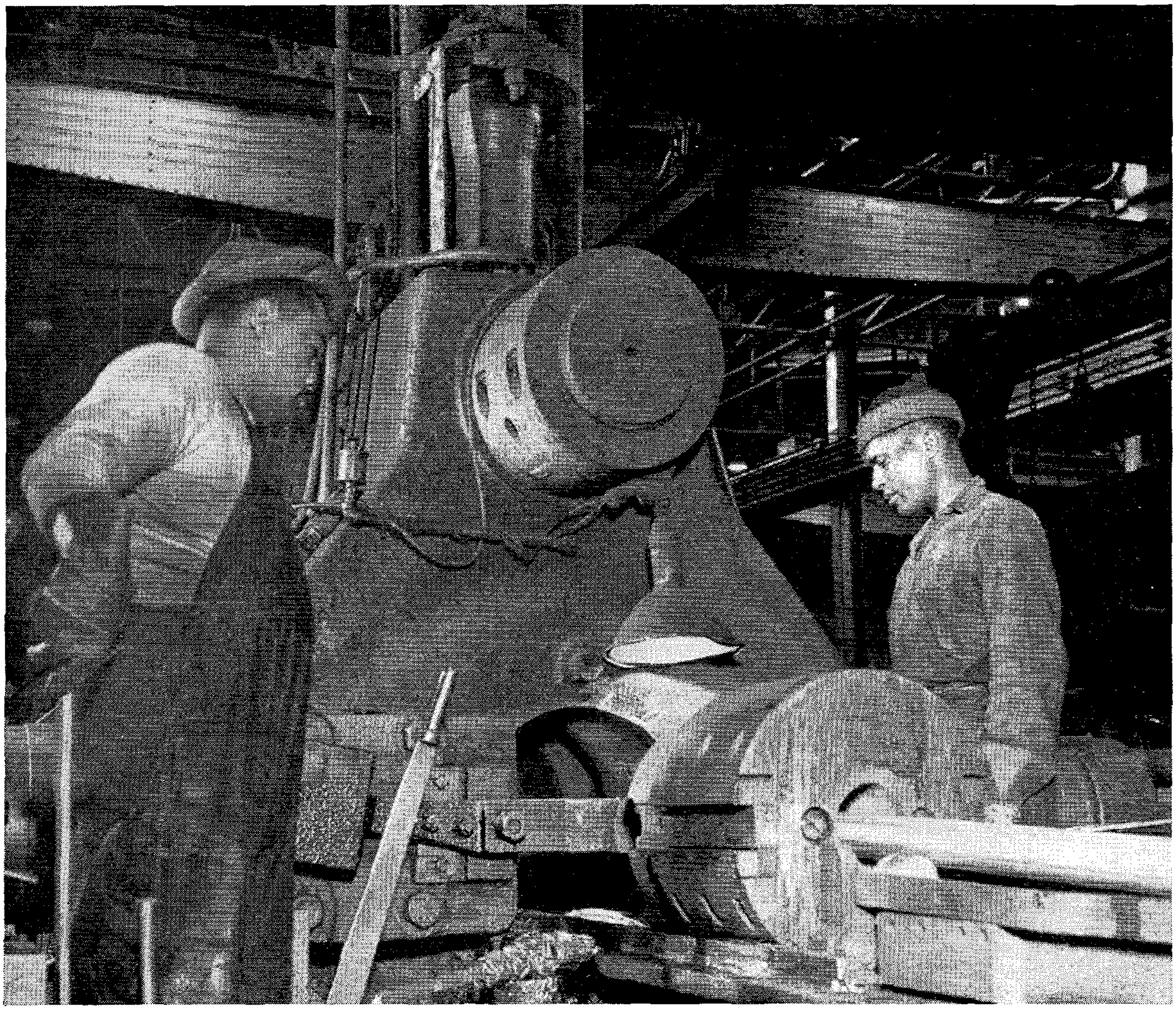


STORAGE BUILDING
SALES
CHEMISTRY
ORDERS
MAIN OFFICE BUILDING
PHYSICS
OFFICE
ROD MILL
GRAND STREET
CARBOLOY DIES
UNLOADING BUILDING
TUBE MILL
CASTING SHOP
OFFICE
POWER HOUSE
ROLL SAMPLES
CASTING SHOP
SWITCHING CENTER
ROLLING MILL
BRINNELL TEST ROOM
OFFICE
TUNNEL
SCRAP ROOM





White-hot molten brass is poured out of an electric furnace into an ingot mold. The steel mold is cooled internally by water to prevent overheating. The ingot, which may weigh several tons, will be sent to one of the mills for processing.



Brass rods and tubes are extruded out of solid stock in long lengths from such machines as that above.

Now, the Bridgeport Brass Company has added another first to its record, being the first company in the United States to install the automatic selective pneumatic tube system[1] developed by Mix and Genest and imported by International Standard Trading Corporation, associates of the International Telephone and Telegraph Corporation. The system uses welded-steel tubing with an outside diameter of 4 inches (10 centimeters), and carriers with an inside diameter of 2½ inches (6 centimeters) by 13 inches (33 centimeters) long. About 1 pound (450 grams) of material may be transported. This size was chosen so that large sheets of paper could be transported without requiring folding.

The Housatonic plant of the company, where the system is installed, covers an area of 32 acres, (130,000 square meters), but it is not necessary to cover the entire area with tube service, since some buildings, such as storage sheds, are not constantly engaged in the hour-to-hour activities of the plant. As mentioned above, the main problem was to expedite the delivery of samples from the casting shop and rolling mill to the laboratories in the main office building, and to help coordinate the activities of the sales and order-writing departments with those of the mills.

It was found that the necessary service could be obtained by installing only 4000 feet of tubing arranged in two loops. On one loop are the sales

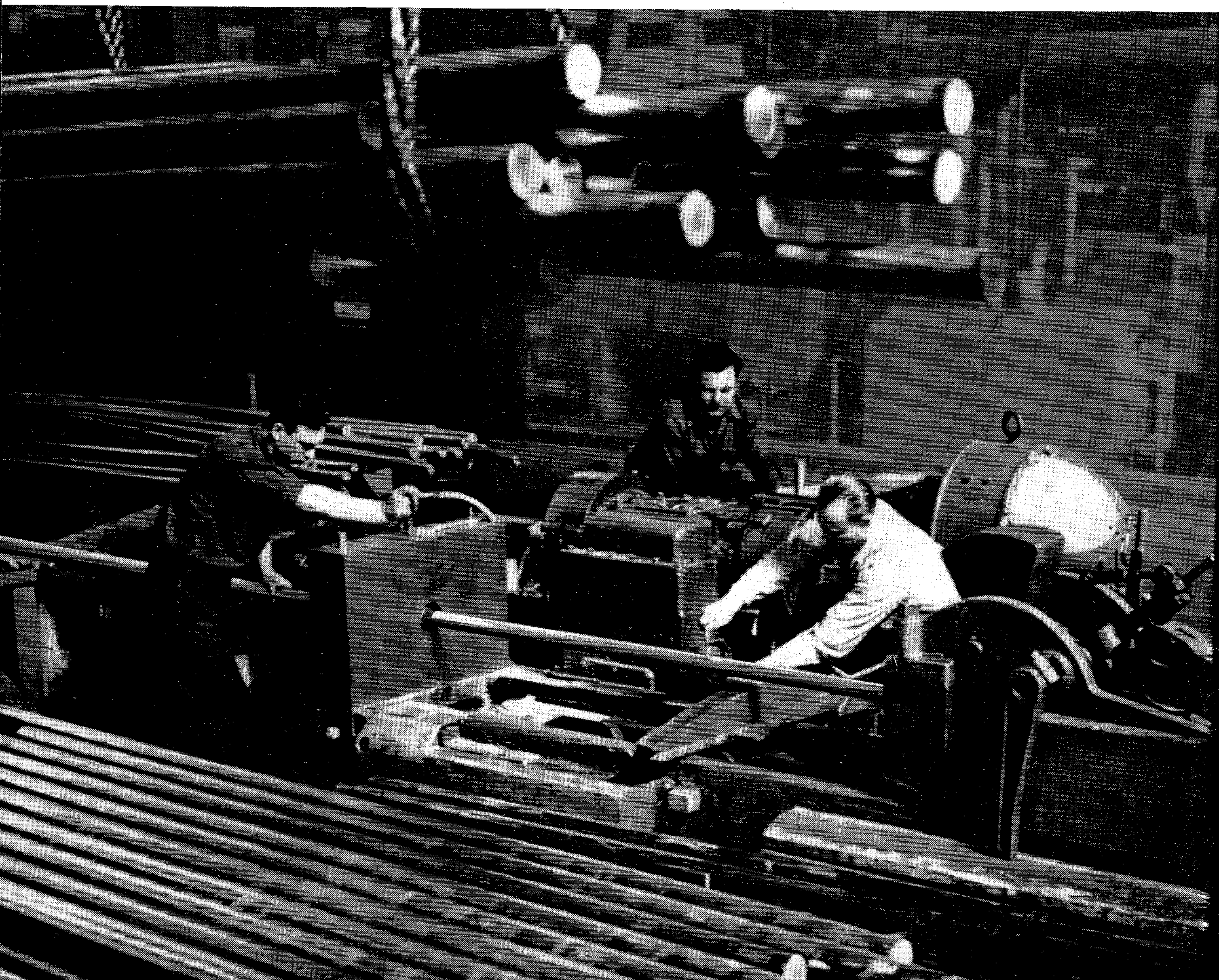
[1] W. Stieber, "Automatic Switching in Pneumatic-Tube Systems," *Electrical Communication*, v. 27, pp. 260–261; December, 1950.

[illegible] chemistry laboratory, physics laboratory, [illegible] department, rod-mill office, and a station from which rolling-mill samples are dispatched. On the other loop are the tube-mill office and the Brinell test room. The switching center is in the rolling-mill office.

Each loop of the system consists of only two tubes, a "go" tube that takes the carrier to the switching center, and a "return" tube that delivers the carrier to the appropriate station. The two tubes pass successively through each of the stations served by the loop. If it is desired at any future time to add more stations to the system, it is only necessary to tap into the existing loop at the appropriate location. This is a distinct improvement from the viewpoints of space requirements, materials, and appearance over the existing manual systems, which require a set of two tubes from the central transfer point to each station.

The method by which the system operates is, briefly, as follows: An employee at, say, the Brinell room sample station will insert a sample into one of the carriers, and turn two rings to the station number of the chemistry laboratory. He will then put the carrier into the "go" tube. The carrier will travel to the switching center, where the number dialed on it will be "read." The switching device then routes the carrier into the appropriate loop, and as it approaches the laboratory, a switching device will shunt it out of the tube and the carrier will drop into the receiver at that station. The carriers travel through the tubes at about 25 feet (8 meters) per second, and it has been found that under conditions of busiest traffic, only 2.5 minutes are required for a carrier to travel between the two farthest stations of the system.

Brass rod being drawn through a die is checked for proper diameter with a micrometer.



Technique of Trustworthy Valves*

By ERNEST G. ROWE

Standard Telephones and Cables, Limited; Footscray, Kent, England

TRUSTWORTHY valves are frequently mechanical re-designs of commercial types to provide improved performance under vibration and shock and are manufactured and tested with such precision as to assure reliable operation for longer lives than would be obtained with their commercial counterparts.

Causes of failures of commercial types are examined and re-designs are made to avoid existing weaknesses. Manufacturing processes are refined to produce more uniform quality and acceptance tolerances are tightened as a continuing check on fabricating accuracy and on the purity of raw materials. The need for long continuous manufacturing runs of given types of trustworthy valves to achieve maximum uniformity of product is stressed.

• • •

The manufacture of valves for commercial radio sets is controlled primarily by the need to produce them at a minimum cost, and despite this limitation it has been possible also to maintain a low failure rate during the normal life of equipment. This fact was particularly noticeable during the second world war when it was clear that, even with the most antiquated radio sets, valve troubles were very much lower than those of other components.

However, the rapid increase in the number of television sets with their average complement of 20 valves against the radio set complement of 5 valves has revealed that the failure risk can be embarrassing and, consequently, manufacturers have been steadily improving their quality within the close confines set by economics.

At the same time, the impetus given during the war to electronic equipment continued with its steady application to civilian purposes such as navigational aids in aircraft and ships, where failure at the worst can lead to disaster and at the best will cause heavy financial losses in "grounded time" etc.

In addition, the fighting services, after the natural lapse of time consequent upon cessation of hostilities, have become increasingly aware of the limitations set on their fighting strategy due to the unreliability of their electronic equipment, and up to the present the valve has come in for most attention on this account.

1. *Definition of Reliability*

An engineer interested in the subject of "reliable" valves very quickly realizes that any attempt to give an accurate definition of reliability depends very much on the application in which the valve is used. Is one to refer to a 1000-hour vibrational condition, to a non-vibrational life of 50,000 hours or more, to a high shock reliability for a very short period, to a long shelf life?

One of the best general definitions is that a reliable valve is characterized by having a very high probability that it will operate normally when taken from stock and installed in equipment for which it was intended and an extremely low probability that it will fail during subsequent operation in that equipment for some definite period of time.

In many cases, the work involved can progress along similar lines to achieve any or all of the above requirements, but for the purposes of this paper the discussions will relate only to valves to be manufactured in large quantities and required to operate reliably for not more than one or two thousand hours under conditions where extremes of ambient temperature may be encountered either in storage or in operation and where the valve and equipment may be subject to considerable mechanical shock or vibration. To be still more specific, the immediate objective is to achieve valve types having characteristics corresponding to existing designs but with a failure risk of the order of 1 per cent in 1000 hours. This achievement is planned to be obtained by refinements of design, materials, and manufacturing methods.

* Reprinted from *British Institution of Radio Engineers Journal,* v. 11, pp. 525–540; November, 1951.

2. *History of World Progress*

The subject of valve reliability has been exhaustively investigated in the United States where various military and civil authorities have quoted the valve as being responsible for more than 50 per cent of the equipment breakdowns. The commercial air lines took the initiative by sponsoring a project with Aeronautical Radio, Incorporated, for the purpose of improving the life of the valves they used. This organization has succeeded in keeping track of the valves used in the air lines and in obtaining an analysis of the failures. The information thus obtained has been used to improve the design of the particular valves concerned and it is reputed that they are now at least 10 times as reliable as they were.

In parallel with this, the United States armed forces have been working on similar lines but more slowly due to the fact that the range and complexity of their electronic equipment is so much greater.

The major programmes have been as follows:—

A. Bureau of Ships *W* series, which are strengthened counterparts of existing types and are primarily intended to withstand gun-fire shock.

B. Aeronautical Radio, Incorporated, series of miniature types.

C. Radio Corporation of America special red tubes.

D. Sylvania and Raytheon sub-miniature tubes.

TABLE 1

AMERICAN RUGGEDISED TUBE TYPES

Equivalent Types Shown in Parentheses

Maker	Metal	Glass	7-Pin Miniature	9-Pin Miniature	Sub-Miniature
Bendix	*6U6W*	*5838 (6X5)* *5852 (6X5)* *5839*			
Chatham		*OC3W* *OD3W* *5R4WGT* *6H6WGT* *25Z6WGT* *2050W*	*6AL5W*		
General Electric	*6SK7W* *12SK7W* *5659 (12A6)* *5660 (12C8)* *5661 (12SK7)*	*5Y3WGT* *5824 (25B6)*	*6AK5W* *6AL5W* *6AQ5W* *6AS6W* *5654 (6AK5)* *5725 (6AS6)* *5726 (6AL5)* *5749 (6BA6)* *5750 (6BE6)* *6005 (6AQ5)*	*12AY7* *5670 (2C51)* *5686 (6K6)* *5751 (12AX7)* *5814 (12AU7)*	*5797* *5798*
Radio Corporation of America	*6AC7W* *6SK7W* *5693 (6SJ7)*	*5691 (6SL7)* *5692 (6SN7)* *2X2WA*		*5879*	
Radio Valve	*5732 (6K7)* *5961 (6SA7)* *6006*	*5871 (6V6)*			
Raytheon		*2C50 (6SN7)* *2C52 (6SL7)* *6J5WGT* *6SA7WGT* *6SJ7WGT* *6SN7WGT* *12J5WGT* *5694 (6N7G)*	*6AJ5W* *6AK5W* *6AL5W* *6AS6W* *6C4W* *6J6W* *6X4W* *5654 (6AK5)* *5725 (6AS6)* *5726 (6AL5)* *5962*	*5670 (2C51)* *5686 (6K6)*	*5702 (6AK5)* *5703 (6J5)* *5704 (9006)* *5744 (6K5)* *5784 (6AS6)* *5851* *5967* *5968* *5969* *5970* *5971* *6051*

Some evidence of the extent of their programme is shown in Table 1.

Work in this country has been centered on types in the Services Preferred List and mainly on miniatures and sub-miniatures. We have concentrated on the miniatures and novals as will be seen in Table 2, but it is evident that the production of the whole range of trustworthy types must take some substantial time yet and careful consideration has therefore been given to interim measures. We have worked on the selective treatment of standard types and, contrary to the experience in the United States, have found that it is possible to devise vibrational and ageing methods that will select a markedly improved product from ordinary commercially manufactured stock. This has been proved on a number of miniatures and novals and on three

TABLE 2

TRUSTWORTHY TYPE VALVES AVAILABLE FROM STANDARD TELEPHONES AND CABLES, LIMITED; MARCH, 1951

Trustworthy Type	Commercial Equivalent	Description
13D2	*6SN7GT*	Double Triode, $\mu = 20$
5749	*6BA6*	Vari-Mu Radio-Frequency Pentode
5750	*6BE6*	Heptode Frequency Changer
6042	*25SN7GT*	Double Triode
6057	*12AX7*	Double Triode
6058	*6AL5*	Double Diode, Separate Cathodes
6059	*6BR7*	Low-Noise Amplifier, Pentode
6060	*12AT7*	High-Slope Double Triode
6061	*6BW6*	Output Pentode, *6V6GT* Characteristics
6062	*5763*	Radio-Frequency Amplifier, Pentode
6063	*6X4*	Full-Wave Rectifier
6064	*8D3*	High-Slope Radio-Frequency Pentode
6065	*9D6*	Vari-Mu Radio-Frequency Pentode
6066	*6AT6*	Double-Diode Triode, $\mu = 70$
6067	*12AU7*	Double Triode, $\mu = 20$

TABLE 1—*Continued*

Maker	Metal	Glass	7-Pin Miniature	9-Pin Miniature	Sub-Miniature
Sylvania		*2A3W* *5U4WG* *6K4A* *6L6WGA* *6SJ7WG* *6SL7WGT* *6SN7WGT* *6SU7WGT* *6X5WGT* *7F8W* *28D7W* *807W* *5930* *5931* *5932* *5933 (807)*	*6X4W*		*6K4A* *5635 (6J6)* *5636 (6AS6)* *5637* *5638* *5639 (6AC7)* *5641 (½6X4)* *5643 (2D21)* *5644 (OB3)* *5647 (½6AL5)* *5718 (9002)* *5719 (½6SL7)* *5840 (6AK5)* *5896 (6AL5)* *5897 (5718)* *5898 (5719)* *5899 (6BA6)* *5900 (5899)* *5901 (5840)* *5902 (6AQ5)* *5903 (12AL5)* *5904 (5718)* *5905 (5897)* *5906 (5840)* *5907 (6AJ5)* *5908* *5916 (6AS6)* *5977 (6K4)* *5987* *6021*
Tung-Sol		*6X4W* *25C6WGT* *5881 (6L6G)* *6000*	*6AK5W*	*26Z5W*	
Others		*3B24W* *6H6WGT* *803W* *811W* *838W*		*5755*	*5851*

GT types, and is based on the selection of many tens of thousands of valves. Therefore, until the full trustworthy programme is completed, it is considered that we can give our customers a worthwhile improvement by special selection methods.

3. Design Considerations

A valve is basically a mechanical structure that has to possess electrical properties that must be maintained throughout its life. Because it is built up from metal, mica, and glass, it is subject to failures common to all structures made of these materials, such as breakage, distortion, loosening of component parts, etc. In addition, the mechanical weaknesses directly affect electrical and chemical properties.

Complete analysis of many large groups of standard commercial valves returned as failures from operational equipment has shown that the faults occurring are as follows:—

A. Electrical failures such as noise, instability.

B. Mechanical failures of the assembly giving short-circuits and open-circuited elements.

C. Mechanical failures of the heater structure.

D. Glass faults.

With the exception of group *A*, these failures agree quite well with the anticipated failures that can be concluded from a careful survey of our own static-life-test results. Group *A* is caused by vibration and is a preliminary to Group *B*, being due to a loosening of the structure

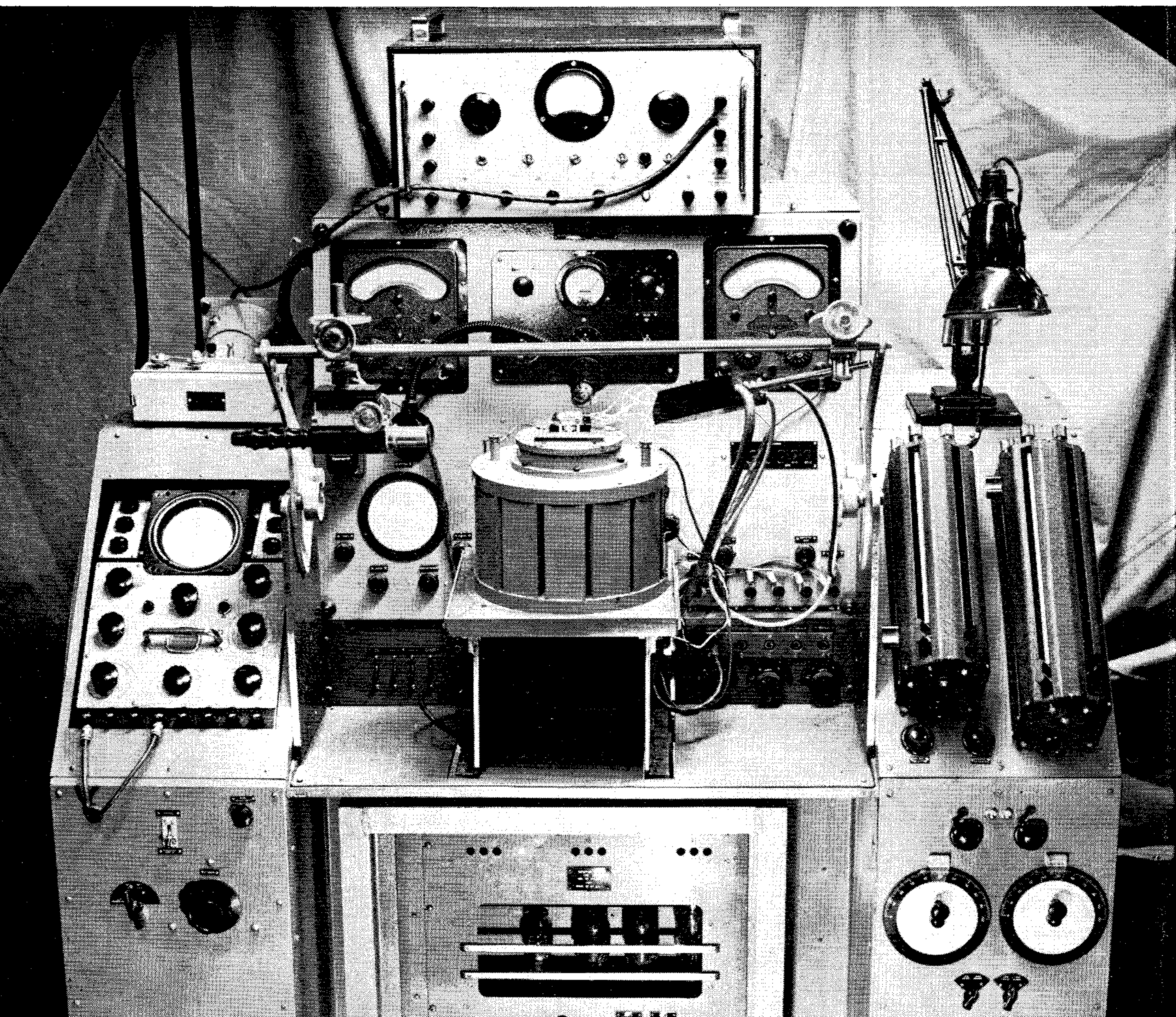


Figure 1—Vibration tests are made with this apparatus.

permitting mechanical movement of the component parts. We can, therefore, sub-divide into three main groups:—

A. Mechanical faults—often aggravated by vibration.

B. Heater faults.

C. Glass faults.

3.1 Improvements to Mechanical Design

It was fairly obvious that re-design efforts had to be directed towards shorter and more rigid structures that would be more stable under vibration. Examination of existing American reliable types showed this to be the trend that they had adopted.

The equipment shown in Figure 1, which was developed by Dr. H. Moss of Electronic Tubes Limited, has been used for studying the mechanical properties of various valve designs. In this, the valve is mounted on a moving-coil vibrator and the alternating-current output of the valve when operated in class-*A* conditions is examined by means of an oscilloscope connected across an anode load resistor. Means are provided for applying a small calibrating signal to the grid of the valve under test so that the noise can be equated to an equivalent voltage on the signal grid, this interpretation of the output overcoming variations in valve gain.

The frequency of vibration of the valve is raised slowly from 15 to 3000 cycles per second with the amplitude of vibration adjusted to give an equivalent acceleration of only 1*g*. It was found that this low order of acceleration ensures that the noise output obtained represents a true picture of the effects of the vibrations of the individual elements of the valves and is not aggravated by the overall vibration imposed on the valve in order to test it. Under these conditions, results can be repeated on any valve with quite consistent regularity.

Photographic records of the noise produced over a frequency range from 200 to 3000 cycles per second by a valve at three stages in its development are shown in Figure 2. These diagrams have two main features:—

A. Sharp resonance peaks, usually in the high-frequency region, which represent true resonance and are usually associated with grid and cathode vibrations.

B. A general noise level in the low-frequency region, which is associated with looseness of the structure and is the more serious fault as this causes noise and instability leading ultimately to short circuits.

A further feature of this testing machine is the provision of a telescope and stroboscopic lamp enabling a vibrating component to be studied when it is in resonance. This is sometimes rather difficult as the other components of the valve may shield the vibrating component from view, and it is often necessary to construct special assemblies to complete the examination.

Modifications to the structural design of

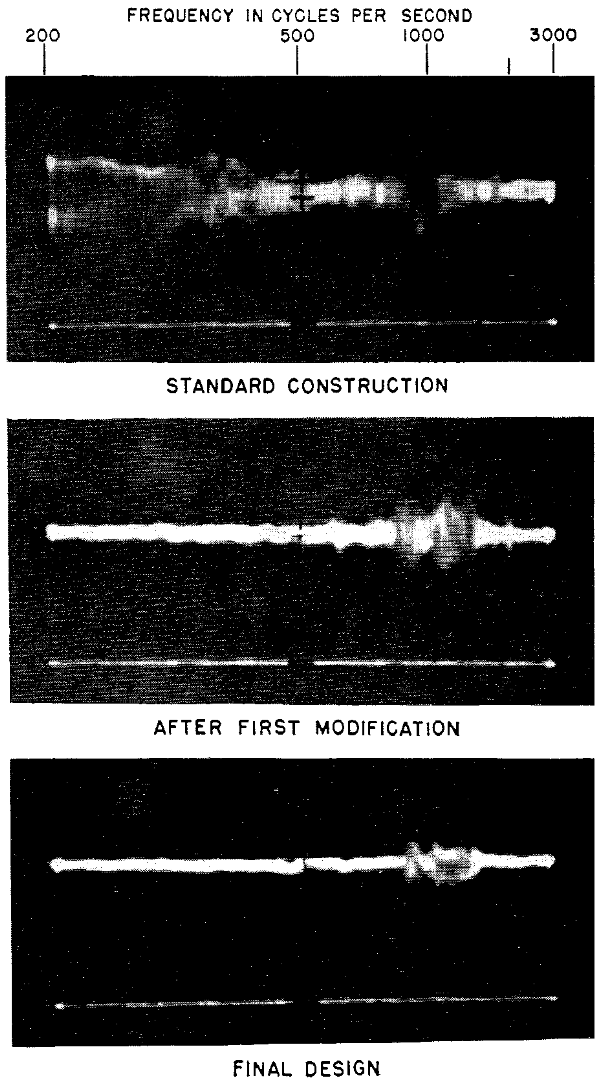


Figure 2—Photographic record of the noise output over the frequency range from 200 to 3000 cycles per second.

valves in the general direction of improved rigidity include the following main features:—

A. Tight mica holes for the grids and the use of double micas of optimum thickness.

B. Locking straps in the micas to hold the grids.

C. Locking the bottom insulator to the stem in as many positions as possible.

D. Locking the anodes into the micas by welding straps across the anode lugs rather than bending them down or twisting them.

E. General changes giving greater strength to the anodes and improved location and fixing methods.

F. Shortening of the valve mount by using increased-diameter cathodes.

G. Minimizing the number of welds.

By applying many of the modifications described, it is possible to produce a resonance diagram as shown in Figure 2 having a very low general level of noise but still showing a few sharp peaks in the upper-frequency region (above 1000 cycles). These latter resonances are in general much lower in height than those of the original valve but usually occur at the same frequencies, indicating that they are fundamental resonances of components and can only be removed by a complete change of design technique. As the immediate aim is to produce valves of similar electrical properties (including capacitances) to an existing range, complete redesign is generally out of the question.

Other machines that are of value in this design work are described later in Section 6.

There is much additional work to be carried out; not only is there scope for improvements on grid making and for closer controls on internal bulb diameters, but there are major projects involved in the studies of cathode base metals and oxide coatings.

3.2 Improvement to Heaters

Heater failures resulting from open-circuits and short-circuits have been due to three causes.

A. Excessive core temperature.

B. Movement of the heater inside the cathode under vibration conditions thereby damaging the heater coating at the cathode ends.

C. Incipient fracturing of the core wire at any sharp bends.

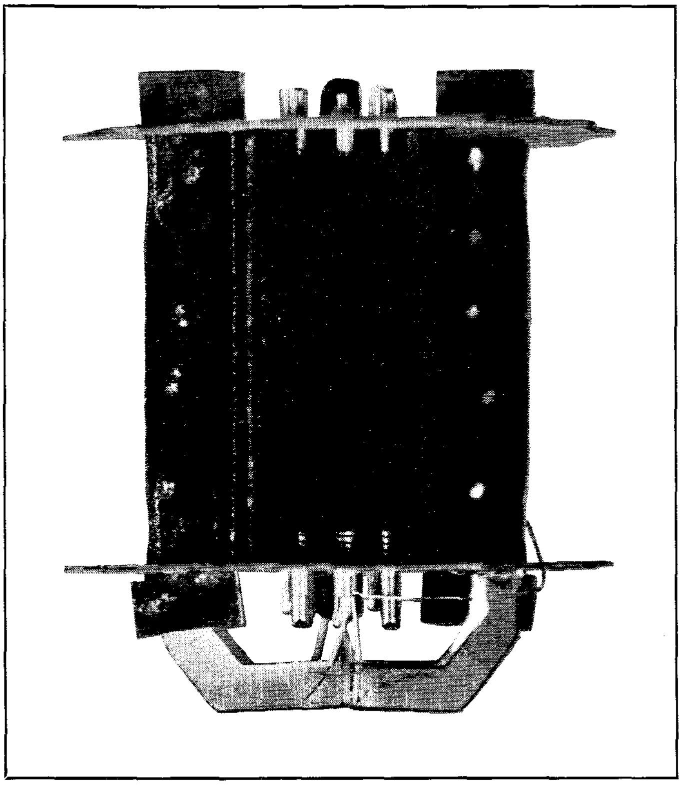


Figure 3—Desirable heater mounting.

It was established that, whilst satisfactory for normal receiving valves, it would be advisable to lower the operating temperature by the use of thicker core wires for the trustworthy valves. The use of these thicker core wires necessitated a longer length of heater wire being employed, which meant extra loops giving a tighter fit into the cathode. The improvement from this change was not as much as was expected, as the heaters still had sharp bends that led to breakage, and there fore the reverse helical heater has now been adopted, permitting the use of a large wire size and also having no sharp bends to cause incipient failure.

This design of heater is now being used for most of the trustworthy valves and it has been found that the core temperature can be kept down to a safe figure, the heater is flexible and has no sharp bends, whilst it fits the round cathode sleeves exceedingly well and is easy to insert into the cathode during assembly without damage to itself.

A further design feature was the use of heater bars that lock into the bottom mica and project below the cathode. The heater can then be inserted into the sub-assembly and welded to the heater bars before the sub-assembly is mounted to the glass base, after which there is restricted space for working. This arrangement may be seen in Figure 3.

Thus we have ensured good heater welds, which can be adequately inspected before the final mount is put on to the stem. Furthermore, the stem wires can be welded to the thick heater bars near the mica periphery giving valuable support to the lower mica and at the same time enabling this weld to be performed away from the congested inner section of the mount.

There is still much to be done to get coatings with the maximum adhesion and freedom from chipping on vibration and shock.

Examples of normal and trustworthy valve designs are shown in Figures 4 and 5.

4. Glass Problems

Glass technology plays a large part in valve making but is not often discussed and therefore it is proposed to outline the general procedures used. For trustworthy valves, the usual methods are still employed, but the controls are very much tighter with *rigid rejection limits* and with *complete batch rejection* if the limits given are exceeded.

As an envelope material, glass has the advantages of transparency, chemical inertness, electrical insulation, hardness, and the ability to be welded by flame heating, but it is a brittle rather than a tough *material and therefore requires a considerable* number of refinements in technique to ensure freedom from cracking in service.

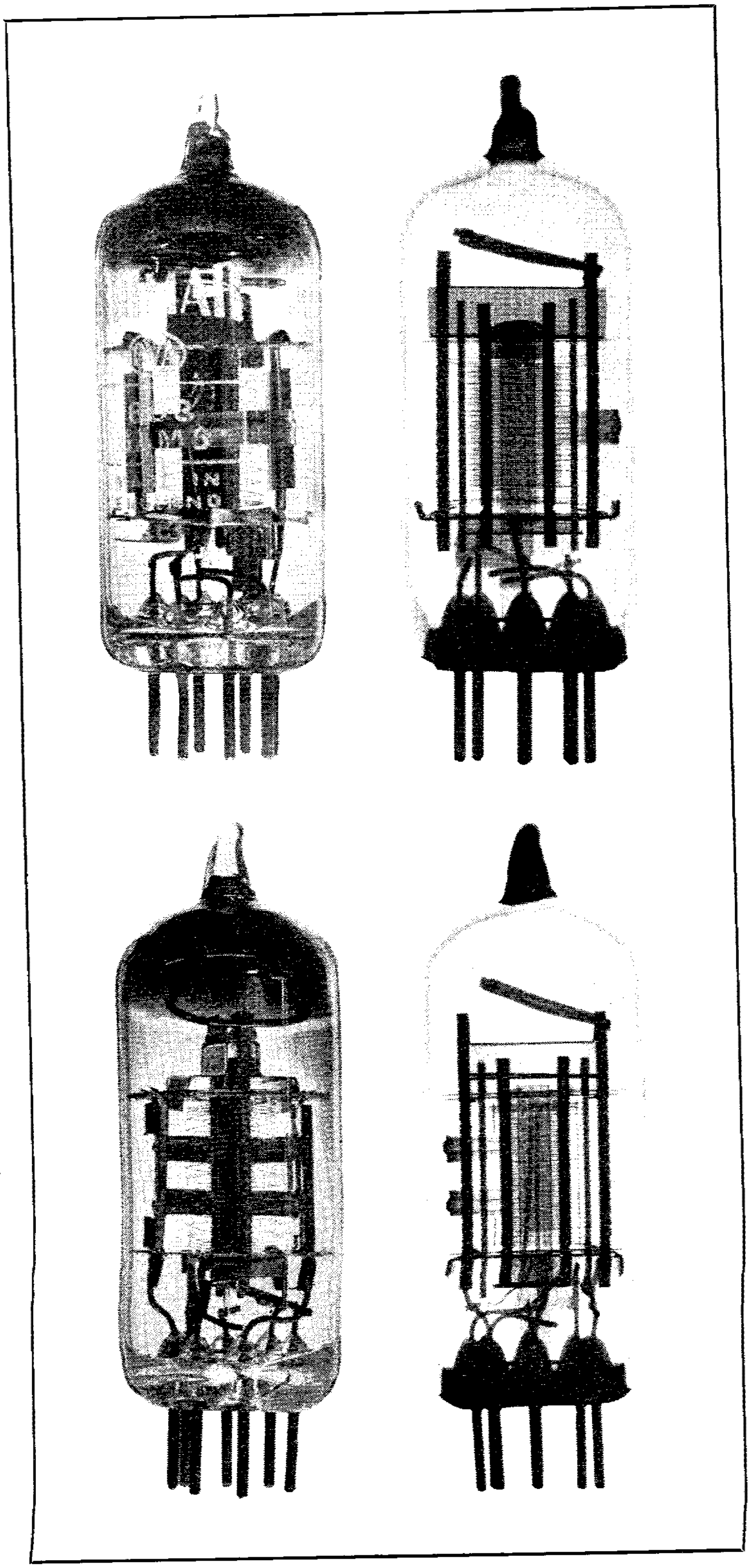


Figure 4—These external and X-ray views of the *8D3* (top) and the *6064*, its trustworthy counterpart, illustrate the use of locked grids, strengthened anodes, improved heaters, and more rigid mountings.

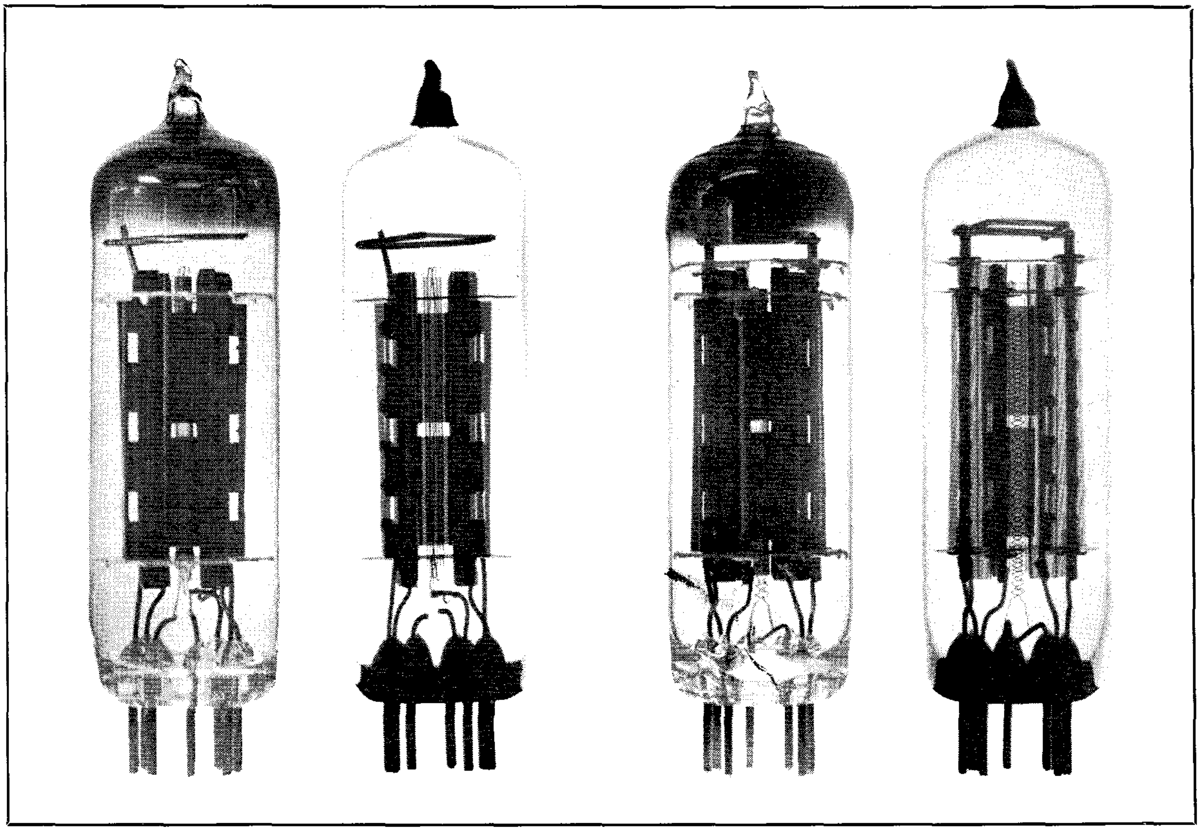


Figure 5—These external and X-ray views of the *6X4* (left) and the trustworthy *6063* show the inclusion in the latter of getter safety mica, additional supports, improved heaters, and more rigid mounting.

Glass is strong in compression and relatively weak in tension and therefore small surface scratches and any crevices are likely to become cracks under quite small stresses. In addition, residual stresses can lead to ultimate failure of glass structures; the two best known are "mismatch stress" arising from the differential contraction of two glasses welded together and "thermal strain" due to the differential contraction of glass near to a weld, relatively to the glass farther away from the weld.

It will also be realized that in addition to glass-to-glass seals there are the problems of glass-to-metal seals that are an inevitable consequence of leading metal conductors through the glass.

Field failures are best studied by considering glass structures in three groups—the pinch types, the loctal types, and the miniature types. Their principal weaknesses are shown in Figure 6. The relative occurrences in the field are best shown in Table 3.

During the fabrication of a valve, a continuous watch has to be maintained in order to limit the shrinkage both internally in the factory and subsequently in the field. The tests employed are a combination of routine laboratory and practical inspection tests on the floor. For ex-

TABLE 3

Approximate Relative Occurrences of Glass Faults in Service

Fault	Possible Reason	Percentage of Group Faults		
		Pinch	Loctal	Miniature
Cracked Base	Thermal Strain or Expansion Mismatch	—	—	65
Cracked Bulb	Rings or Patches of Strain	40	95	20
Crack from Tip Off	Crevice	40	—	—
Cracked Dome	Strain Ring	10	—	—
Bad Tip Off	Crevice	—	—	10
Miscellaneous	Leaks, etc.	10	5	5

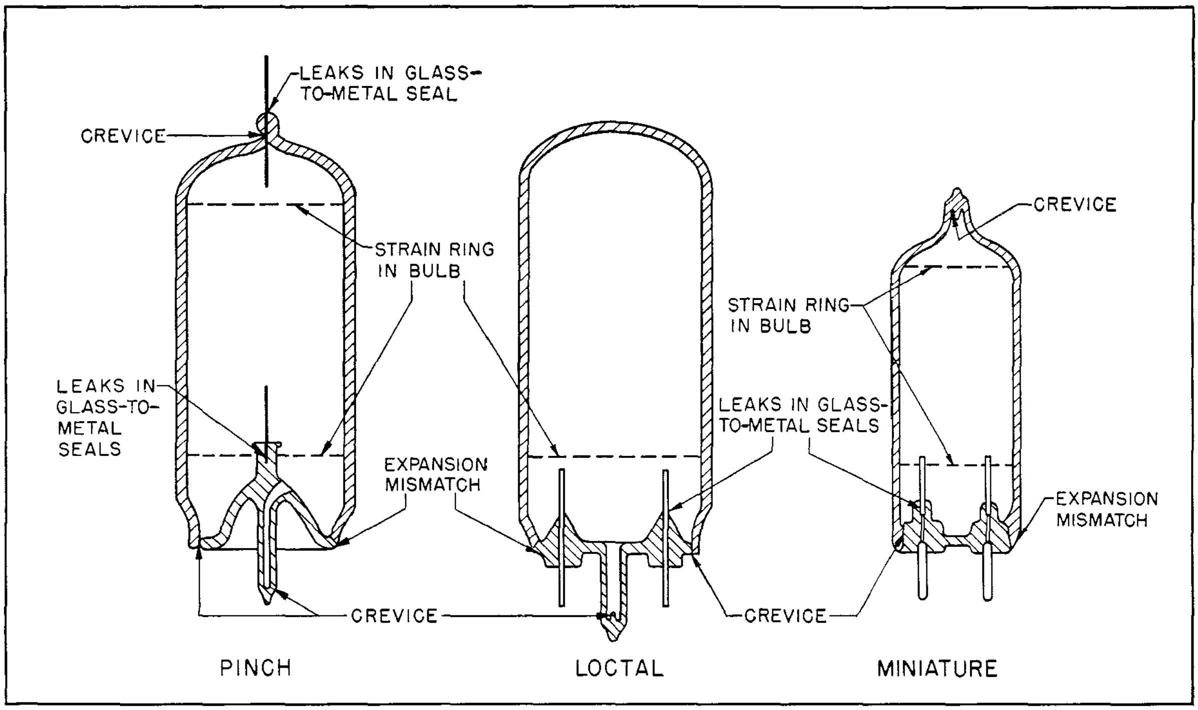


Figure 6—Principal points of weakness in glasswork.

ample, in the laboratory, photo-elastic techniques are used to detect differences in thermal expansions of glasses and also to measure stresses in the bulb walls, whilst the factory uses as its main control the well-known *B* test, in which the pins are distorted by the insertion of a conical steel plug after which the whole is plunged in boiling water. The glasswork must not crack.

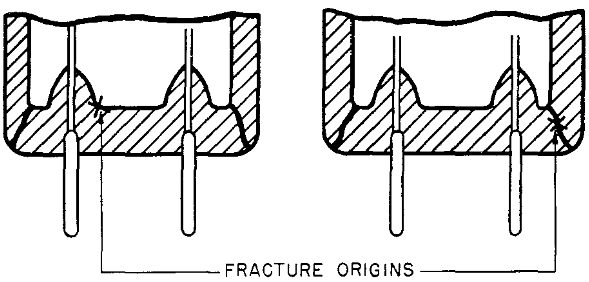


Figure 7—Fracture origins in miniature valves resulting from differences in bulb and stem glasses. At left, the cracked stem occurs when both glasses have the same thermal expansion while the cracked bulb at right is for bulb glass of $\alpha = 98$ and stem of $\alpha = 90$, where the differences are too great.

4.1 Expansion Mismatch

There is not usually much trouble in the field from expansion mismatch because the glasses are suitably chosen to avoid it. It is very important that the glass stem shall always be slightly compressed by the bulb and Table 4 and Figure 7 show the results from combining different commercial glasses to make miniature valves. α is the co-efficient of thermal expansion.

TABLE 4

Effect of Expansion Differences Between Bulb and Stem Glasses of Miniature Valves

Bulb, Lime-Soda Glass	Stem, Lead Glass	
	Lead Glass *A* $\alpha = 92$	Lead Glass *B* $\alpha = 90$
Glass *C* $\alpha = 98$	Satisfactory	Cracked Bulb
Glass *D* $\alpha = 96$	Satisfactory	Satisfactory
Glass *E* $\alpha = 92$	Cracked Stem	Satisfactory

To ensure satisfactory matching, it is important to maintain routine laboratory tests on sealing stress and thermal expansion on all incoming supplies of glass.

4.2 Thermal Strains

To prevent failure due to thermal strain, it is essential to minimise the "strain rings" caused by the sharp thermal gradient due to hot-joining of the glasses.

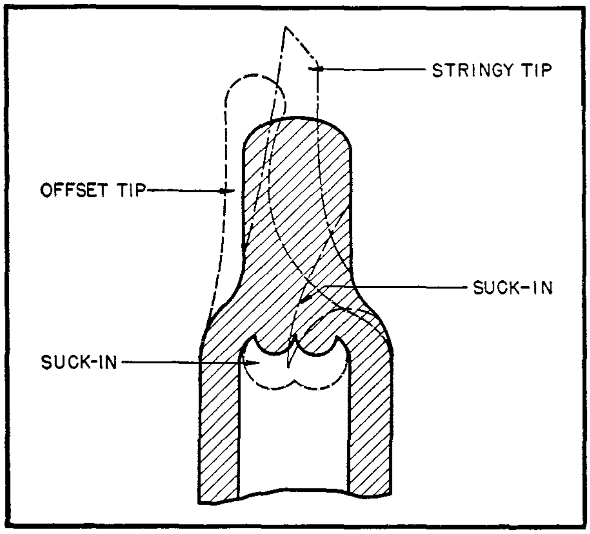


Figure 8—Normal tip-off shown solid with some common defects in broken lines.

The distribution of stress in a strain ring is complex but in general can be regarded as a zone of high tension with the body of the glass protected by a thin layer of glass in compression at the surface. The problem is complicated because where the glass is likely to be subjected to tension forces during life, as is likely in valve sockets, strains are deliberately set-up in the base of the miniature valve to increase its strength.

These stresses are controlled by strain-viewer observation against established standards.

4.3 Crevices

The term crevices is used to describe areas where the glasses join and can form acute angles between their surfaces. An expert operator is able to detect such internal crevices in most glasswork by careful observation of the external contour.

Crevices in the stem-to-bulb seal can be detected by plunging the cold valve into boiling water thereby starting cracks from any flaws on the inside surface.

In the case of "tip-off," it will be seen from Figures 8 and 9 that inevitably there is a potential source of weakness at this point and additional assistance is given to the factory by large chart diagrams and definite external dimensional requirements.

4.4 Leaks

Leaks usually occur because of faulty glass-to-metal seals. Vacuum tightness on these seals depends on a chemical reaction between a tightly adherent oxide layer on the metal and the glass melted on during the sealing operation. The stages of the reaction are usually accompanied by colour changes in the seal and thus one test of vacuum tightness is a visual observation of the seal colour. As a further aid, the valve may be immersed in a mobile fluorescent liquid which, being sucked into the leaky hole, is made visible under ultra-violet light.

Fine leaks can only be detected by storage and characteristic deterioration, but it may be possible to accelerate this by storage in hydrogen at 100 pounds per square inch (7 kilograms per square centimetre).

Successful results depend on very careful

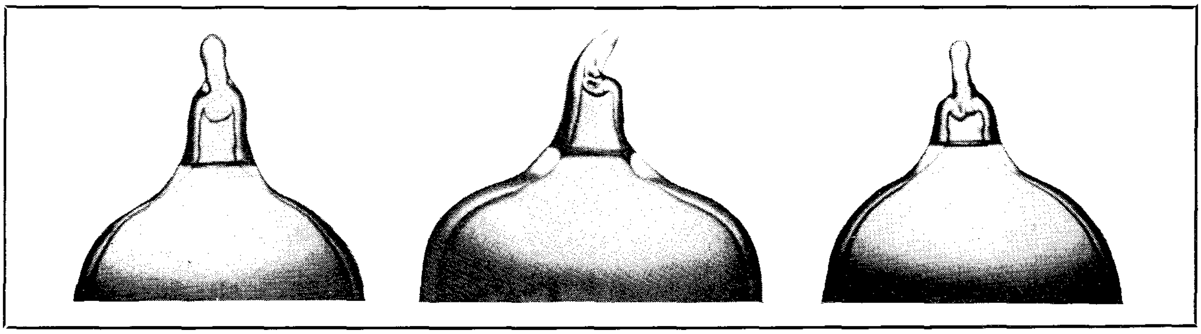


Figure 9—At left is a normal tip, centre one is an offset tip, and at right a tip with air sucked in.

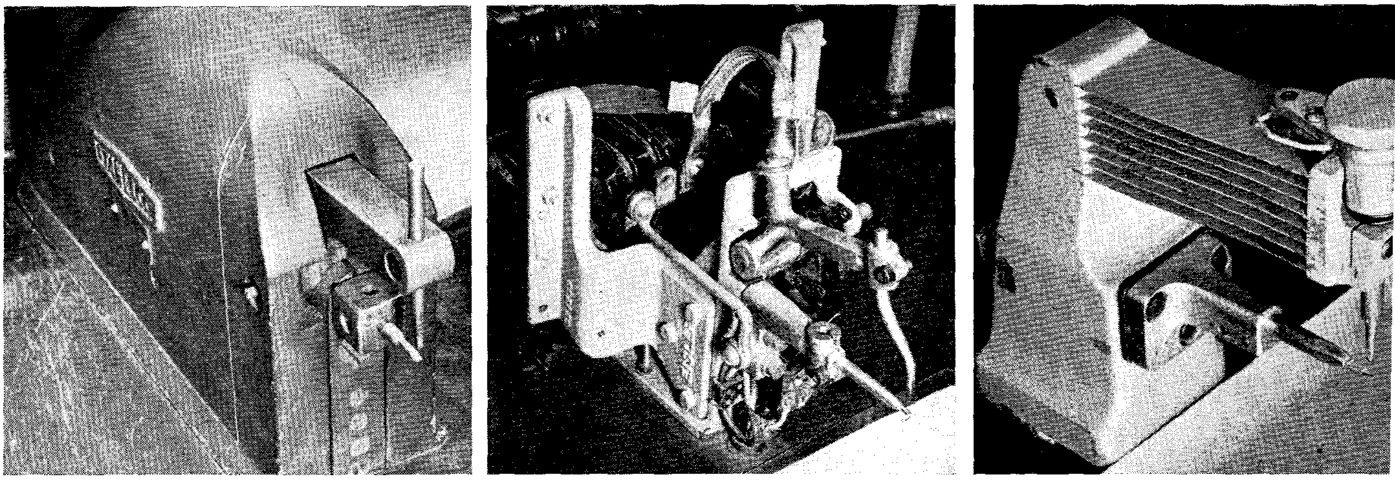


Figure 10—Welder heads of three designs. From left to right are Stanelco, Eisler, and the new Slee.

control of the seal wire used, by tests such as microscopic examination for fissures, and glass sealing tests for co-efficient of expansion.

5. *Manufacture of Trustworthy Valves*

The present state of the art is that the engineer can design reliability into a valve exclusively by calculation and special testing carried out on laboratory equipment. The major problems of reliability then resolve into the adequate control of materials and processes and of the inherent variability of the individual operator.

To meet the first requirements, the raw-material standards are made stricter than is usual and all processing, particularly of coated cathodes and heaters, is more careful and thorough. All machinery used is subjected to routine maintenance controls of a higher requirement than normal. For example, exhaust machines are set up for optimum vacuum performance without undue emphasis on the economic side.

The fact that it is possible for the first time to remove economics as one of the prime controlling factors provides one way of reducing operator variability. Therefore, paying the operator by bonus schemes on quantity and by piece-work rates etc., has been abandoned in favour of time-work, although it is possible that in the future it may be practicable to pay a bonus on a quality basis.

One school of thought advises that reliable valves should be made in an entirely separate location to the commercial types. Much may be said, however, in favour of manufacture of trustworthy valves in the centre of the main assembly groups so that with strong supervisory control the effect of the lessons learned will have a large psychological influence on the whole factory. This is doubly important when it is realised that an international crisis will mean that nothing else but reliable valves will be required.

On assembly operations, the most important variable is resistance-welding, which often relies on the skill of the operator to control the weld. A valve usually has about 20 welds and therefore a high proportion of potentially faulty valves can result from quite a low proportion of faulty welds. We have now designed a welding head and associated timing equipment to give a reliable and repeatable weld.

Figure 10 shows the comparisons between various welders, Slee being our latest development. In addition, benefit has resulted from a close study of the operations involved whereby the job has been graded to a number of accurately pre-set welding machines, restricting the work variation demanded from any one unit.

The second variable is a more elusive one described as "lint." This is descriptive of the various air-borne contaminations such as cloth, fibres, dust, etc., that can get into a valve structure and, by becoming carbonized during subsequent processing, cause variable leakage and intermittent noise in the finished valve. This trouble can be mitigated only by observance of the utmost cleanliness. All components are kept covered; special trays are used between the cleaning operations and the assembly stage;

valves are assembled under a glass cover (Figure 11) which is slightly pressurized by a dry air stream so that the normal air current is away from the valve and the assembly operators wear special overalls made of lint-free cloth. Finally, completed assemblies are placed in their bulbs immediately after inspection and the bulbed assemblies are kept in closed boxes. The valves are sealed-in and exhausted with the minimum of delay.

It is of considerable importance that the inspection should be capable and thorough. As may be seen in Figure 12, this work is done using binocular microscopes and is controlled by chart methods.

It will be appreciated that the uniformity of product that is desirable in a trustworthy valve can be achieved only by continuous and long production runs. It is only by being ruthless that the standard can be maintained and therefore both the beginning and the end of such a run may be diverted for use as normal radio valves or else scrapped rather than run the risk of premature failures in the field.

and group *B* tests, which are sampling tests to check on the level of quality.

6.1 Group-*A* Tests

These tests are mostly 100-per-cent tests on which the basis of batch rejection will be affixed, say 5-per-cent rejection from the batch.

Such testing starts at the completion of the assembly stage with a visual inspection of the mounts using a binocular microscope.

At the sealex section, special checks are carried out to ensure satisfactory glass quality of the completed valves. These consist of a visual inspection of the tip-off for quality and a thermal shock test to the completed valve which will show up strained bulbs and bases.

The valves then pass to the activation stage and tests are applied here to detect short-circuits and any lint in the valve by applying 250 volts to each electrode in turn with all other electrodes grounded.

A heater-flash test is carried out where a high voltage is applied instantaneously to each valve for a period of ten seconds; this serves to sort out possible heater failures.

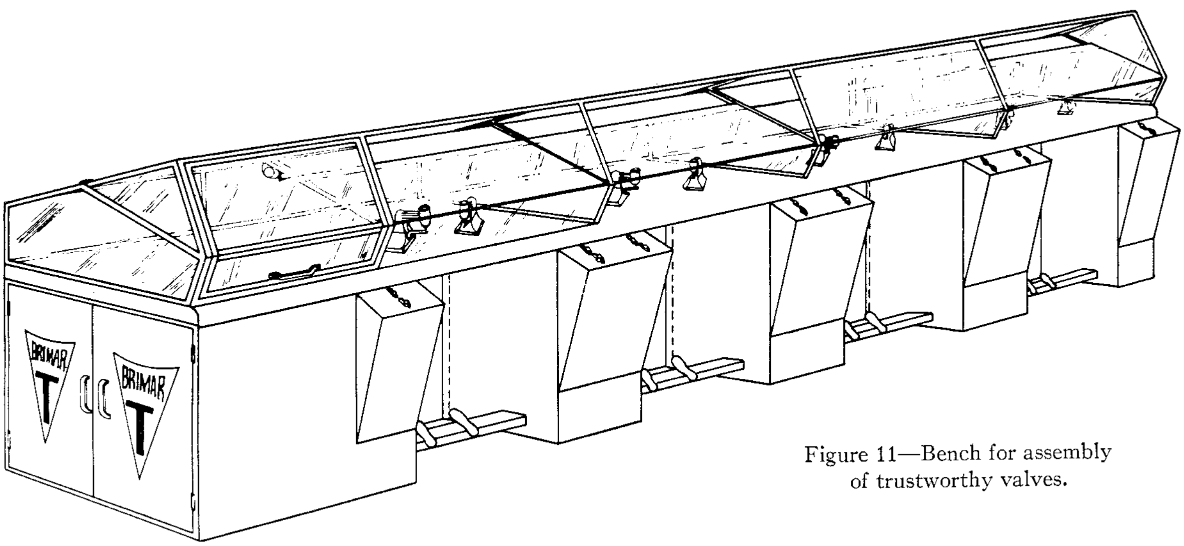


Figure 11—Bench for assembly of trustworthy valves.

6. *Testing of Trustworthy Valves*

Adequate control has to be maintained by batch manufacture and by progressing valves accordingly through the test procedure.

These tests are shown diagramatically in Figure 13 and consist of group-*A* tests, which are factory tests to ensure that the valves are uniform and line up with the design specification,

The valves after activation are subjected to 100-per-cent electrical test for characteristics and a 100-per-cent short-circuit test. All valves are then given a 10-hour life run under class-*A* conditions followed by a repeat electrical test. Figures are recorded on a sample of 12 valves

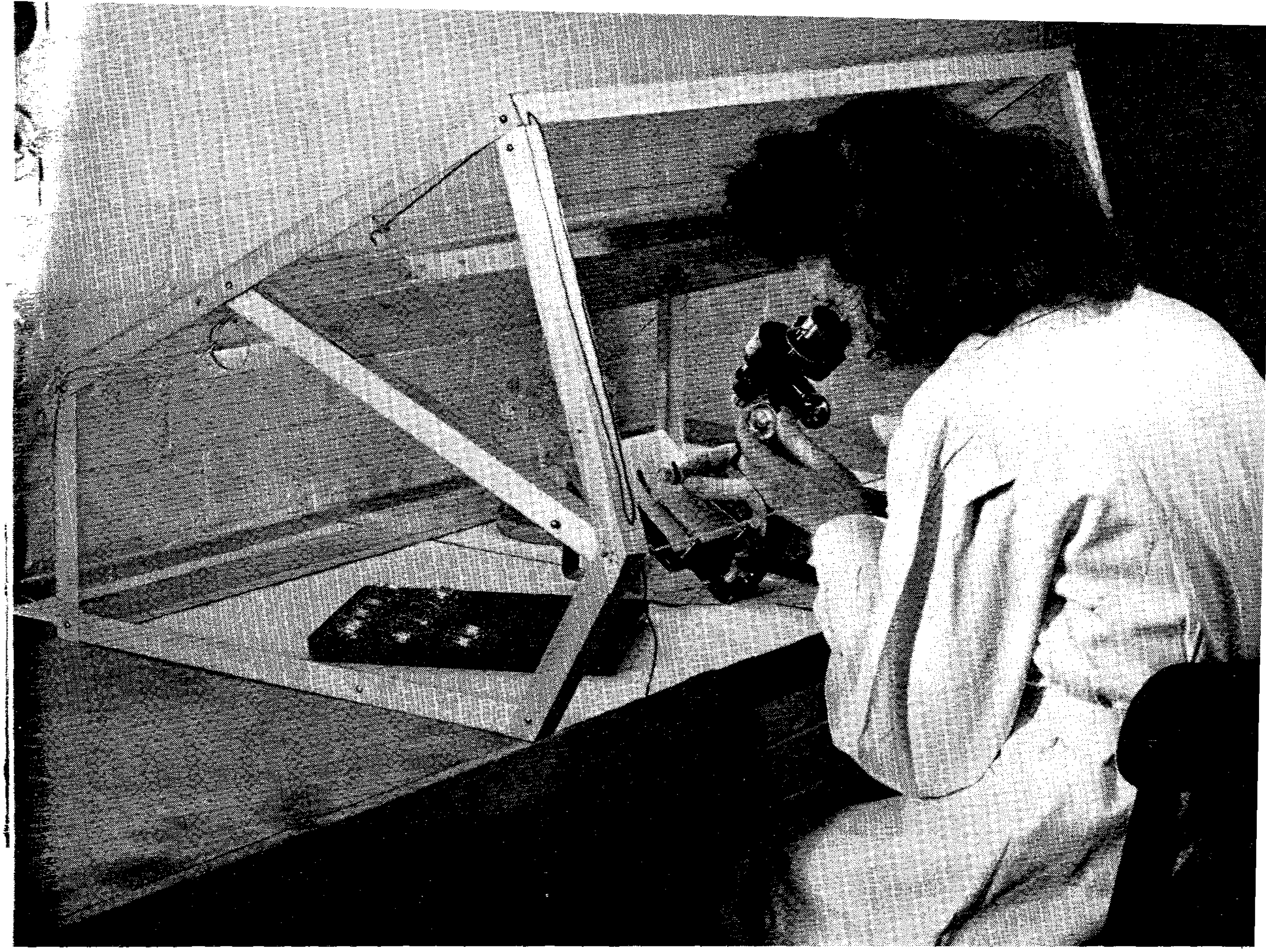


Figure 12—Inspection position for trustworthy valves. The operator looks into the microscope through a glass panel.

measured before and after the 10-hour run. These figures are compared to assess what changes in characteristic have taken place during this period.

6.2 Group-*B* Tests

Such tests are quality-control tests made on samples taken from the batch at various stages in manufacture to determine that the original quality is being maintained and are in most cases destructive tests, i.e., the valves utilized for the tests must be scrapped after test and cannot be returned to the original batch.

At the sealex operation, envelopes are tested for the presence of strain rings by a diamond scratch procedure that will cause spontaneous cracks if excessive strain is present.

After the valves have been given their 10-hour run and re-tested for electrical characteristics, sample batches of 8 valves are taken and subjected to the following range of mechanical tests.

6.2.1 Vibration

Vibration at 50 cycles per second with an amplitude of ± 0.020 inch (0.5 millimetre) for a period not less than one minute but not more than two minutes in each of the three planes of the valves, i.e.,—

A. Horizontally with the major axis of the valve perpendicular to the plane of vibration.

B. Horizontally with the major axis of the valve parallel to the plane of vibration.

C. Vertically.

Throughout these tests, the valves are operated under class-*A* conditions and the noise outputs measured across the anode load resistor are noted. Afterwards the sample valves are

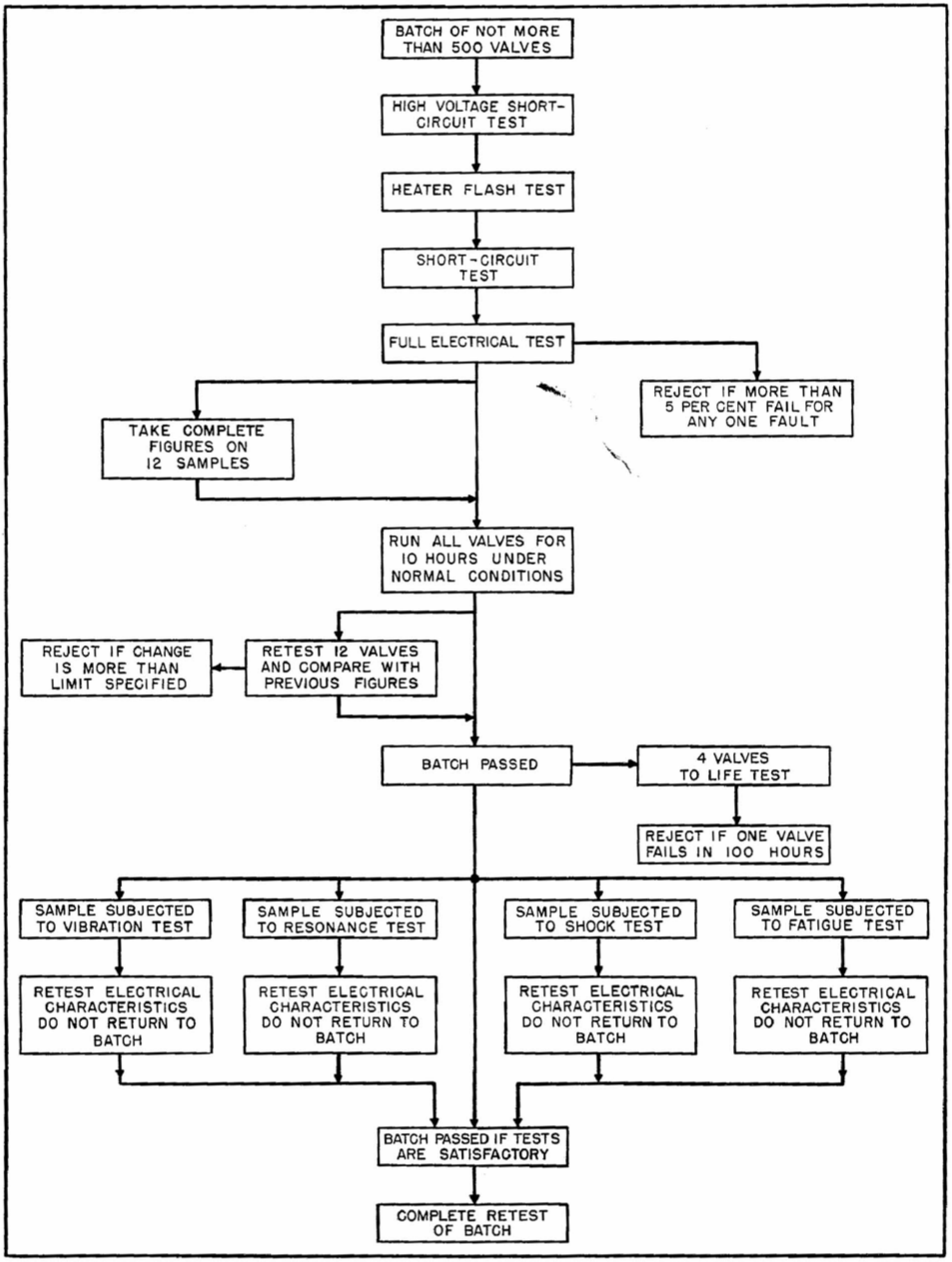


Figure 13—Testing procedure for trustworthy valves.

re-tested and any valves having noise outputs exceeding the limit during vibration, or failing to pass the electrical test after vibration, are rejected.

6.2.2 Resonance Test

The sample is checked for resonance on the design apparatus and points of resonance are recorded and compared in position and height with the standard laid down by the design engineer.

6.2.3 Shock Test

For the shock test, the sample valves are mounted rigidly on a moving platform that is subjected to impact shock from a falling hammer. The apparatus is shown in Figure 14. The valves are operated cold and are given five blows in each of four positions, these positions being as for the vibration test except that in the case of the vertical position the shock is applied from both ends of the valve. The magnitude of shock imparted to the valve during this test is of the order of 1000*g*. and the valve is monitored for short circuits occurring during the shock. After shock tests, all valves are electrically re-tested.

6.2.4 Fatigue Test

The valves are vibrated in the three standard positions for prolonged times of the order of 90 hours each at various spot frequencies and amplitudes giving accelerations of the order of 2 to 3*g*. During the vibration period, the heaters are switched on and off at a 5-minute cycle and

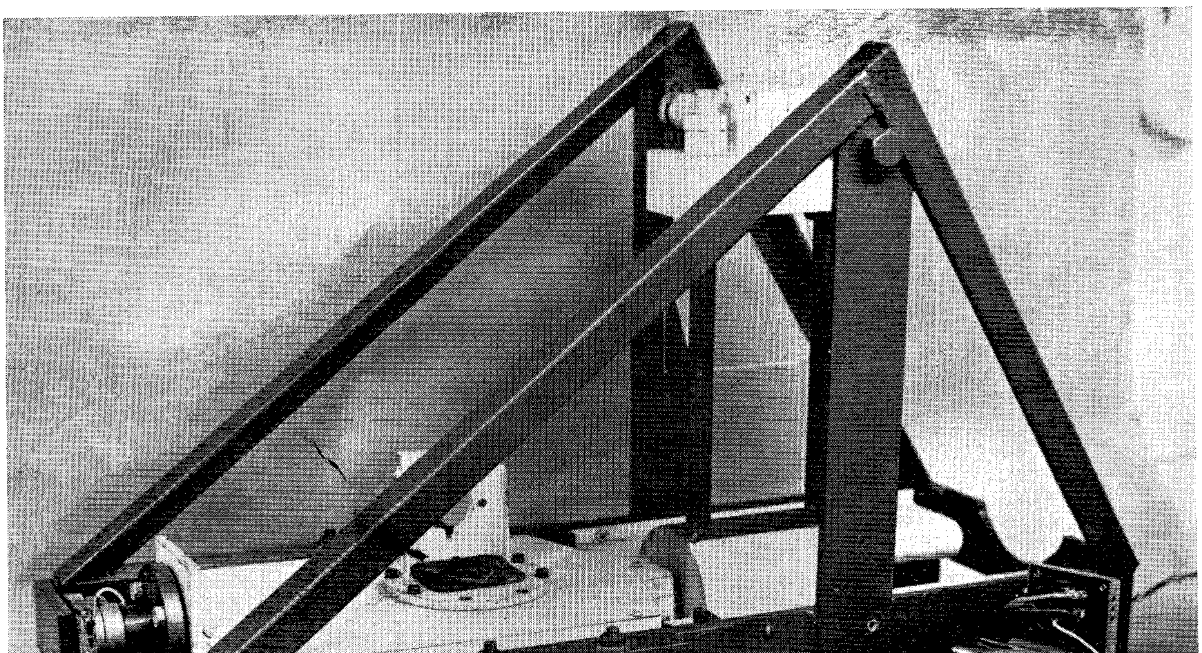


Figure 14—Apparatus for impact shock testing.

the valves are monitored in class-A operating conditions for excessive noise in the anode resistor. It is considered that the occurrence of noise in an anode resistor under vibration is indicative of a loosening of an electrode that will ultimately cause a short-circuit or open-circuit failure. In this manner, the noise monitoring gives an early indication of a probable failure. Figures 15, 16, and 17 refer to this equipment.

6.2.5 Life Test

A batch of the valves is run on normal static life test for a period of 2000 hours starting after the initial electrical test. The results of the life test are studied at the conclusion of the vibration tests (usually two weeks after the valves have been placed on life) to give an indication of the early life behaviour of the batch.

At the conclusion of the above range of tests, the remainder of the batch, which has not been subjected to the vibration test, is

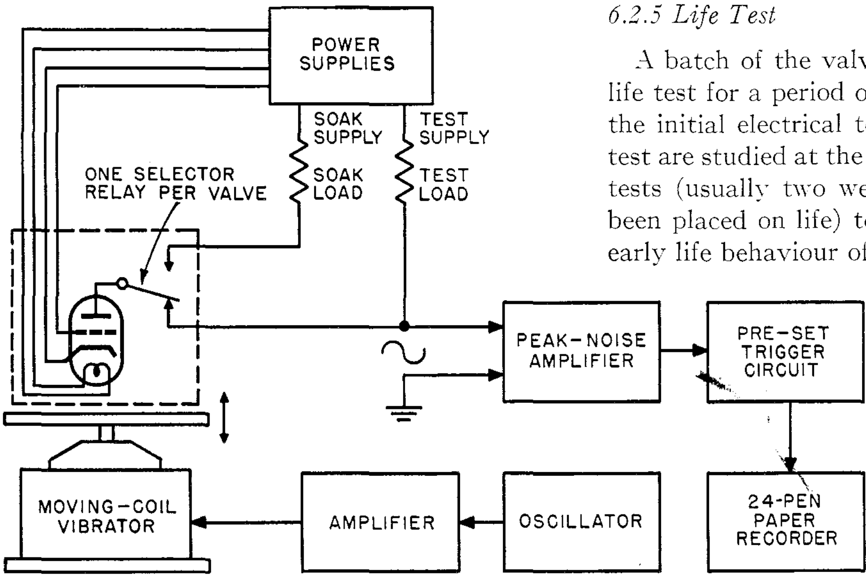


Figure 15—Schematic of fatigue-test machine.

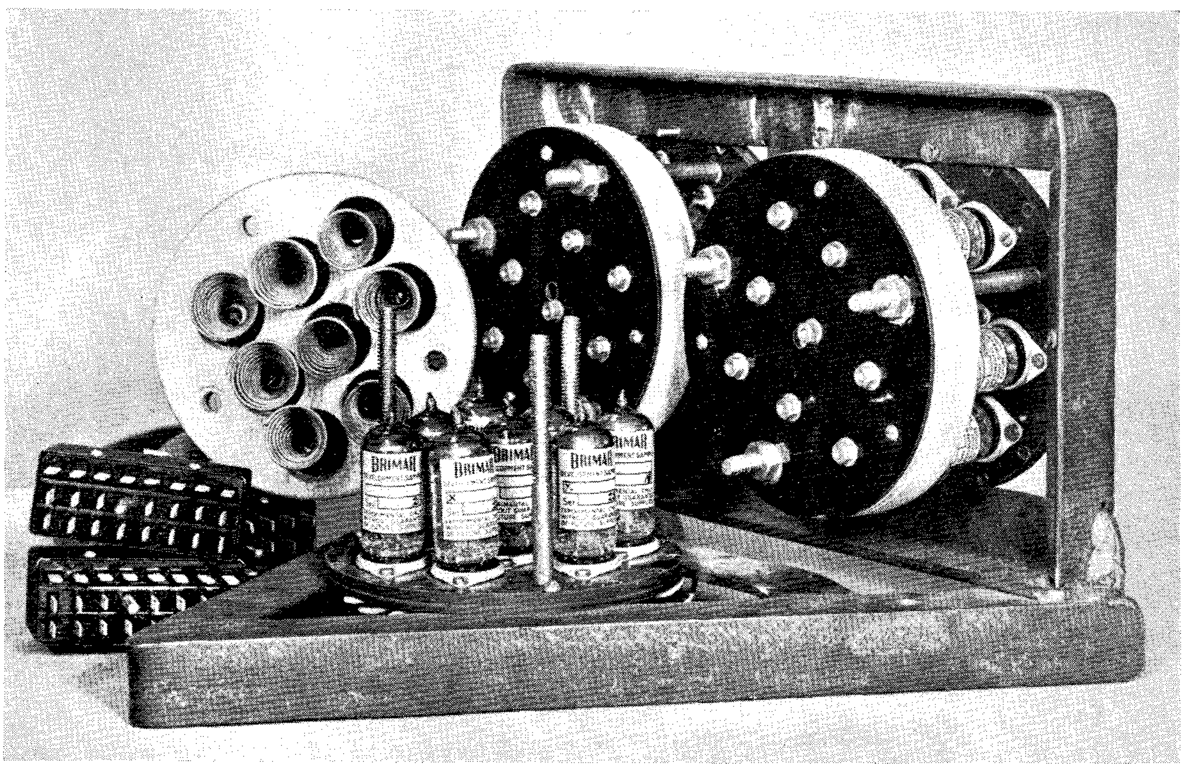


Figure 16—A group of valves is mounted on each of three disks that are fastened to a frame in the standard vibration positions. Three of these frames are shown mounted on a vibration table.

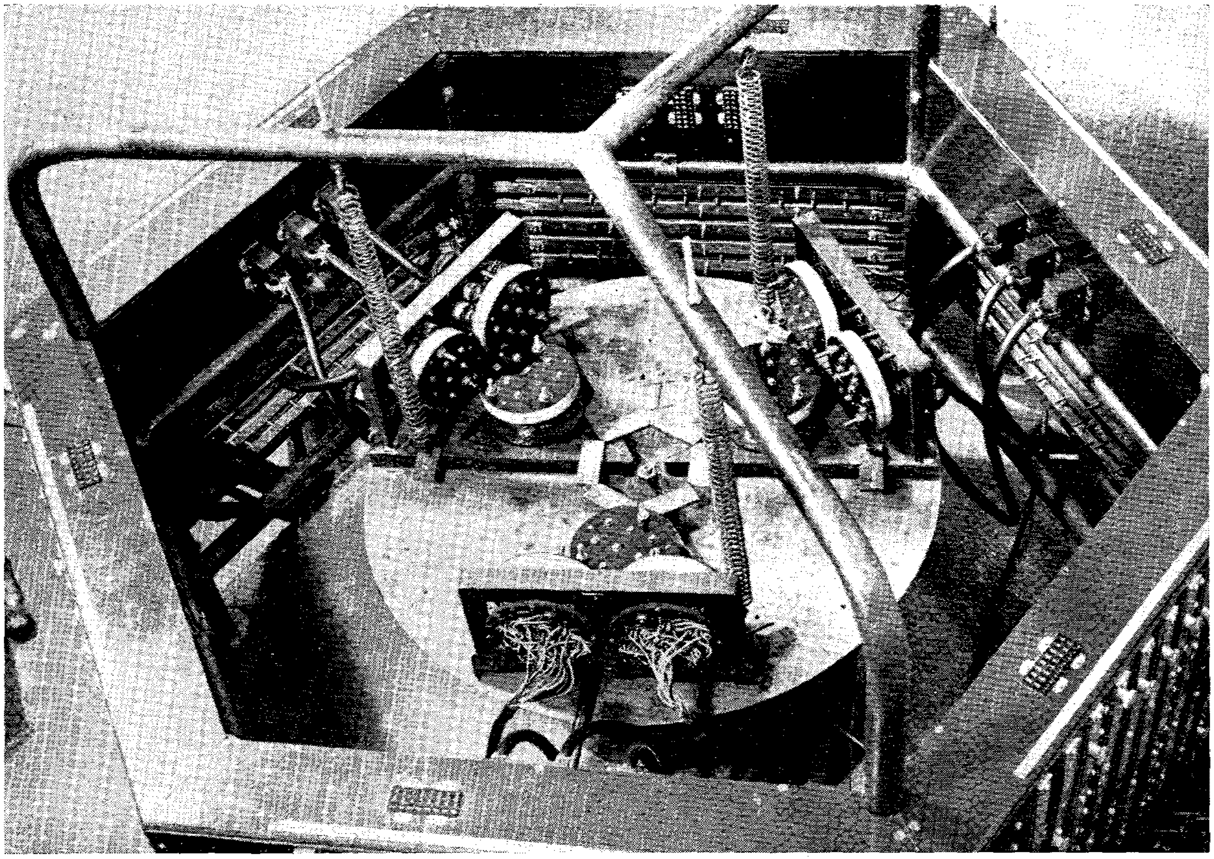


Figure 17—Vibration table on which three frames, each carrying three groups of valves, are mounted. Wiring from the sockets goes to the connector strips on the outer surface of the machine.

re-tested once more to determine any failures occurring on storage.

Throughout the above tests, a double sampling system is employed (see Figure 18) and the fate of the batch as a whole depends on the results of the samples subjected to each of the individual vibration tests.

By this means, it is possible to ensure that the quality rating of the valve in manufacture remains up to the standard required by the design engineer. Full records are kept on each batch so that at any time later reference may be made to the initial test history of a valve.

7. *Assistance from the Customer*

7.1 Conservative Operation

It must be appreciated by the equipment designer that a valve cannot have the safety factor of other components and in case of misuse will often act as the circuit fuse. D. D. Knowles of Westinghouse in a recent article put over this truth in the following words:—

> If valves could form a union, the first thing they would do would be to strike on the grounds of discrimination, speed-up, and hazardous working conditions.

It is essential that designers should not use valves when another device would be more suitable, should be ultra-careful to select the correct valves for the job, should operate all valves at conservative ratings, and should always design for a "safe" failure.

Reliability can only be achieved by the closest co-operation between equipment designer and valve manufacturer. The valve-makers' advice, not only on the conditions of use, but on the methods of connection, valve-holder tolerances, soldering requirements, etc., must be scrupulously observed if the desired results are to be obtained.

Another aspect of this co-operation is to get assurances that circuits will accept valves made in the widest possible electrical limits. The proportion of reliable valves required will steadily increase and in the event of an emergency will immediately become 100 per cent of the valve manufacturers' production; thus any necessity for the selection of a limited range of characteristics would be little short of calamitous.

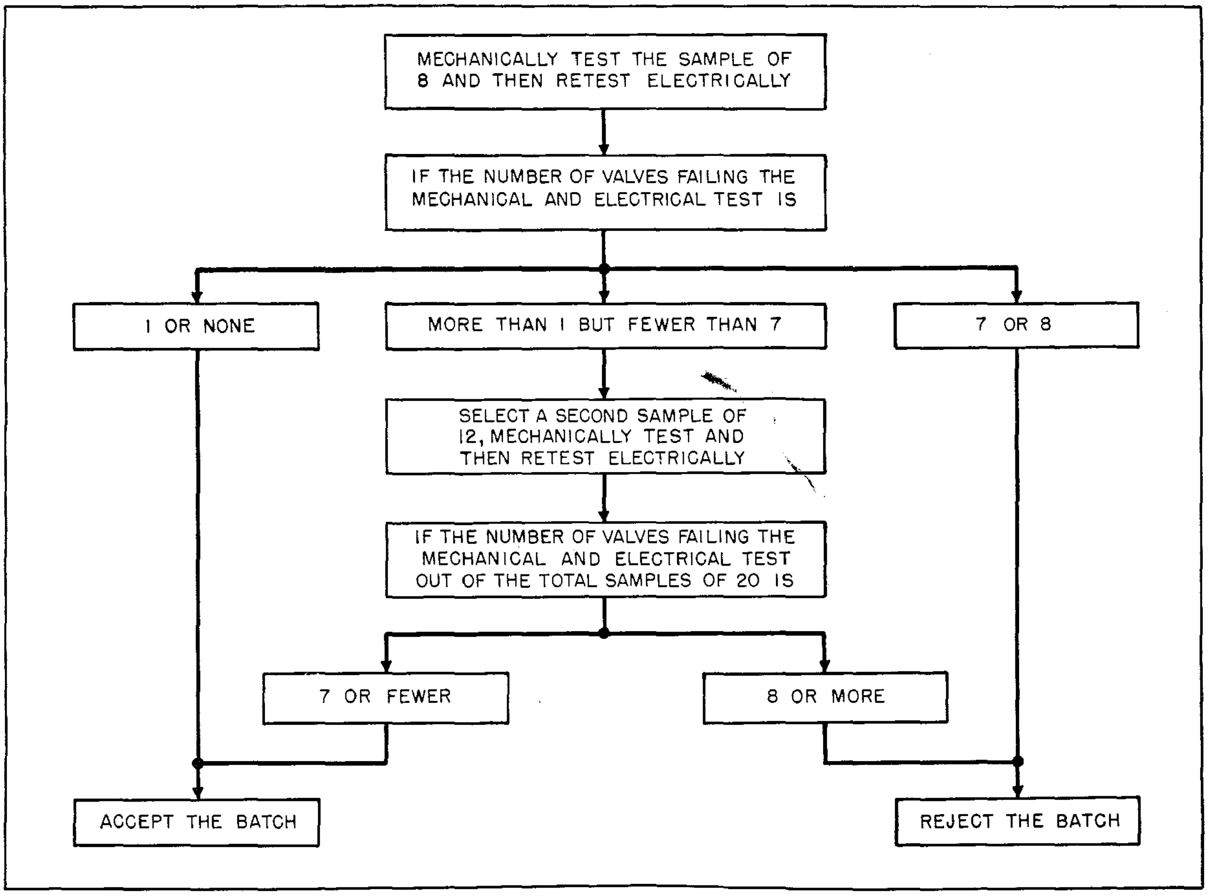


Figure 18—Double sampling procedure.

7.2 Type Diversity and Continuous Production

It is a well-known axiom that high reliability can only be obtained from valves having a high yield in manufacture, i.e., a low production shrinkage, and that such a state can be achieved only by uninterrupted production over a considerable period of time. It is therefore imperative that the valve maker shall have adequate orders to enable him to achieve this condition and that the number of types involved shall be as restricted as possible. The success of the project depends on circuit designers confining themselves to a short list and being prepared to use more valves of these types rather than employing still another type that may be more elegant technically.

7.3 Field Reports

No matter how difficult it may be to organize, the valve maker must be given adequate information from the field regarding the performance of his valves, because it is these data that enable him to maintain an accurate correlation between field conditions and the many test machines designed for factory usage. It is appreciated that with equipment distributed all over the world, often in the hands of semi-trained personnel, this requirement is not easy to meet, but it has been solved by both the American and Canadian air lines and determined attempts are being made in this country to see that the valve manufacturer is not hamstrung from lack of information.

8. Shape of Things to Come

Whilst the main effort at present is directed towards making reliable replacements of existing types, it is very important to consider the way to go in the future.

The biggest stumbling block to ultimate reliability of glass-based valves is the valve-holder. The valve manufacturer has recognized the problems of incompatibility between valves and valve-holder and has compromised by specifying the use of a wiring jig to centralize the socket contacts during circuit assembly and of a pin-straightening-jig for the valve pins before insertion into the valve-holder.

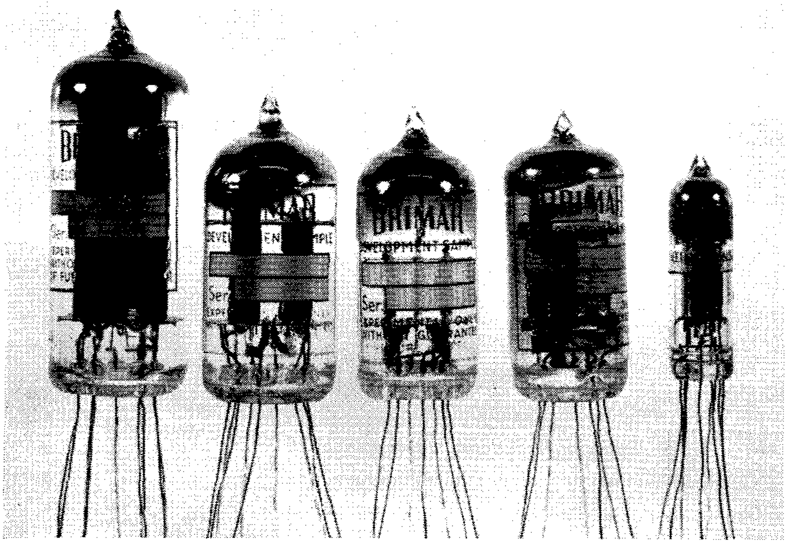


Figure 19—Flying-lead valves having from left to right the electrical characteristics of the *6CH6*, *12AU7*, *6AL5*, *8D3*, and a sub-miniature pentode.

Despite all this, considerable evidence has been secured that semi-skilled personnel can cause a "mechanical insertion loss" of 3 per cent or greater, and whilst this can be reduced by careful education, the requirement of 1 per cent in 1000 hours is easily swamped by this single possibility.

Because of the inevitability of this loss, it is probable that the reliable conventional type of valve of the future will have flying leads and will be soldered into the circuit. The size of the envelope will be dependent on the dissipation requirement, and the sub-miniature will be employed for low-dissipation needs with the miniature (18.5-millimetre, 0.73-inch) and noval (20-millimetre, 0.79-inch) types being used for better characteristics and higher dissipation.

Photographs of such types, which are now available, are shown in Figure 19.

9. Conclusion

In conclusion, evidence so far obtained shows that early life failures, which are the cause of most of the heartburnings, are due almost entirely to mechanical and glass troubles.

If these are eliminated by attention to design and manufacturing methods, together with a short life run, there is a great hope that for at least 1000 hours the failures will be negligible. However, correlation between factory tests and field experience can only be achieved with large-scale usage of these better valves after which it is quite possible that with user co-operation the valve maker will be able to issue guarantees showing actual failure rates.

It is a hazardous thing to prophesy but within five years the reliability of the valve can be such that the present criticisms will then be directed towards other components. As reliability work must inevitably take considerable time, adequate pressure should be maintained on manufacturers of other components to ensure that all the constituent parts of an equipment keep in step on this matter.

10. Acknowledgments

My thanks are due to many members of the staff of Brimar Valve Division, who have done the work described and have assisted in the preparation of this paper; also to the Admiralty for permission to publish parts of the work done on their behalf.

Line testing at "Morro Frio."

Application of 12-Channel Carrier to the Open-Wire Line Between Rio de Janeiro and São Paulo

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TWELVE-CHANNEL carrier telephone systems have been operated on open-wire lines quite extensively since the first type-*J* systems were installed in the late thirties; in many countries, the operation of the equipment has became standard practice and the equipment itself has been described in detail in this[1] and other journals.

On the other hand, each application has presented its own special problems from the line point of view and detailed information on the solutions found for such problems has not been widely published. It was thought, therefore, that a description of a comparatively complicated case from the point of view of an operating company, together with a survey of the results obtained in practice, would be of interest to many transmission engineers. The particular installation to be described is the application of four 12-channel systems to the open-wire line between Rio de Janeiro and São Paulo in Brazil.

Considerable detail has been given purposely for engineers faced with a similar type of problem. Those who prefer only a general view are advised to pass over Sections 3, 4, and 5 (except 5.1 and the latter parts of 5.2 to 5.4 and 5.6) dealing with the test results.

[1] D. P. J. Retief and H. J. Barker, "SOJ-12 Open-Wire Carrier Telephone Systems in South Africa," *Electrical Communication*, v. 24, pp. 310–323; September, 1947.

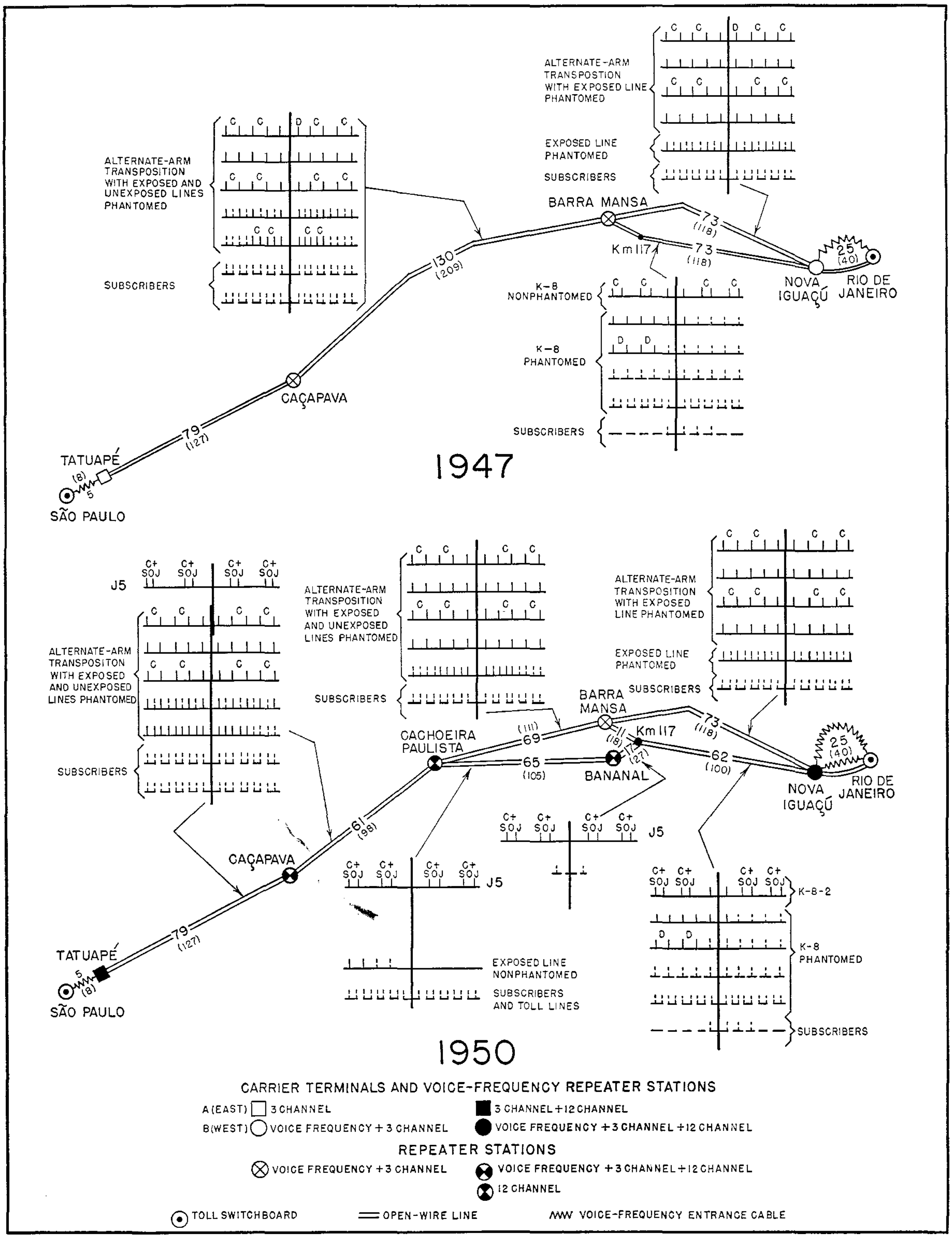


Figure 1—The line between São Paulo and Rio de Janeiro in 1947 and in 1950 after the installation of the four 12-channel systems. The dotted lines indicate that the facilities are equipped for only part of the section. Distances are in miles (kilometers). Carrier terminals are at Tatuapé and Nova Iguaçú; toll terminals at São Paulo and Rio de Janeiro.

1. Line Problem in 1946

1.1 Existing Line

The first open-wire telephone line between Rio de Janeiro and São Paulo was established in 1918 when one phantom group was connected using mechanical repeaters near the midpoint of the line. Later, more wires were added and carrier systems were applied until by 1947 there were 62 through circuits (of which 36 were obtained by 3-channel carrier systems) as well as a considerable number of shorter-distance circuits.

The upper part of Figure 1 shows some of the main details of the line and repeater-station spacings as they existed in 1947. Nova Iguaçú and Tatuapé were established as the *B* and *A* carrier terminal stations, serving Rio de Janeiro and São Paulo, respectively, and connected to them by loaded voice-frequency cables. The corresponding American designations are "West" and "East," respectively, which, in this case, are almost exactly reversed geographically. Barra Mansa and Caçapava were 3-channel carrier and voice-frequency repeater stations.

Figure 1 indicates also the transposition schemes applied to the line and the number of through pairs (nonthrough pairs being shown dotted). More detailed accounts of the transposition arrangements of the parts of the line on which the *SOJ* systems were to operate are given in Section 3.

From Nova Iguaçú to Barra Mansa, there were two separate lines; the "old" line was transposed to the alternate-arm transposition system[2] on the first and third crossarms, and a line built in 1938, which passed through a point known as "Km 117," was transposed to the *K-8* system. From Barra Mansa to Tatuapé, the line was transposed to the alternate-arm transposition system on the first, third, and fifth crossarms.

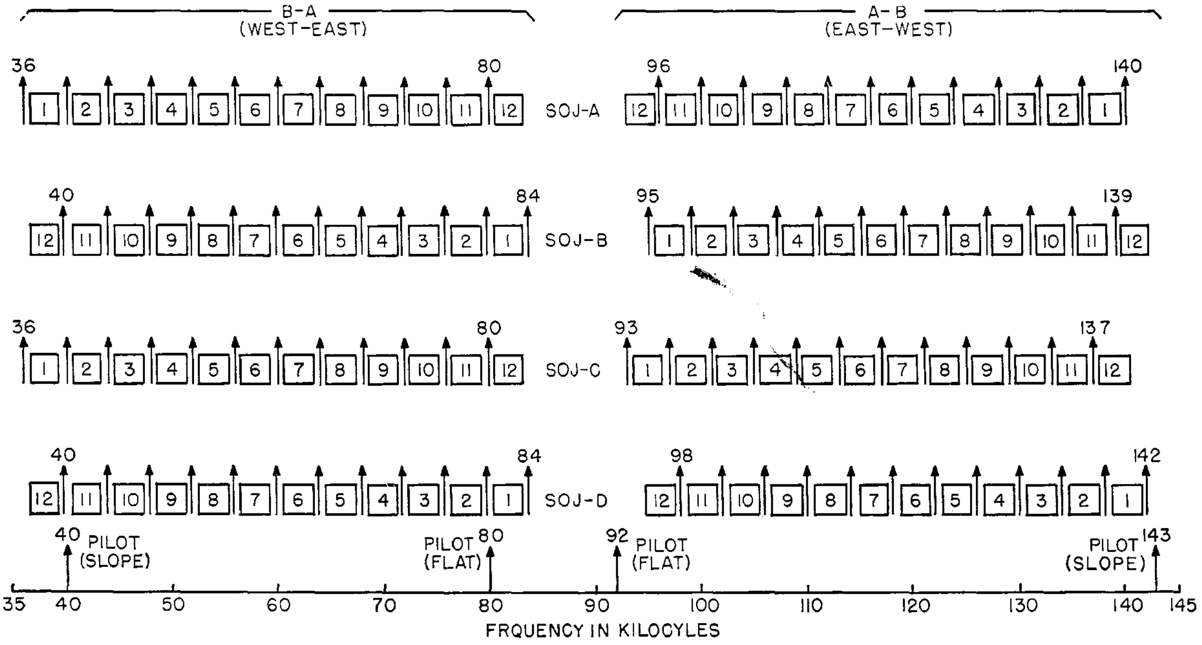


Figure 2—Frequency assignments for the four *SOJ-12* systems.

1.2 Planned Arrangement

By 1946, the *SOJ* repeater-station spacings and the general layout of entrance and lead-in arrangements had been planned and all the equipment for four *SOJ-12* carrier systems (types *A*, *B*, *C*, and *D*)[1] had been ordered from Standard Telephones and Cables, Limited, of

[2] All the transposition systems mentioned in this article, except where otherwise stated, follow Bell System nomenclature.

London. The frequency assignments of these four systems are shown in Figure 2.

A new piece of line about 82 miles (132 kilometers) in length was to be built between Km 117 and a point on the existing line at Cachoeira Paulista, passing through Bananal.

The *SOJ* terminals were to be installed in Nova Iguaçú and Tatuapé with repeaters in Bananal, Cachoeira Paulista, and Caçapava. New buildings were to be constructed in Bananal and Cachoeira Paulista and four of the existing *C* carrier repeaters were to be moved from Barra Mansa to Bananal.

At all stations, terminal poles existed or could be established within 50 yards of the equipment with the exception of Nova Iguaçú, where a filter hut was to be built; here line filters were to separate the *SOJ* and *C* frequencies, which were to be led-in over an existing quadded toll entrance cable about 525 yards (480 meters) long, the *C* frequencies on the existing *C*-loaded pairs, and the *SOJ* frequencies on unloaded pairs to be chosen as the result of measurements.

1.3 Problem

The chief line problem to be solved was that of preparing about 200 miles (322 kilometers) of existing line and constructing about 80 miles (129 kilometers) of new line in such a way as to enable the four *SOJ* systems to operate within reasonable limits of noise and cross talk under all but exceptional weather conditions.

For the section of new line from Bananal to Cachoeira Paulista, the choice of the details of line construction to be applied was comparatively simple since this was to be a complete *SOJ* repeater section. For the section of the new line from Km 117 to Bananal, the wire spacing and gage had to be the same as for the Nova Iguaçú-to-Km 117 section so as to avoid the introduction of impedance irregularities, but the other details could be chosen as required.

For the sections of existing line between Nova Iguaçú and Km 117 and between Cachoeira Paulista and Tatuapé, the problem was far more complicated. This article is mainly concerned with detailing the methods used to prepare these sections of line and with the test results obtained when the modifications had been made and the *SOJ* systems were operating on the line.

2. Cross-Talk and Noise Limits

2.1 General

Before planning the details for the preparation of the open-wire line, it was clearly necessary to fix the transmission limits for those characteristics of the *SOJ*-derived circuits that were likely to be affected by the characteristics of the open-wire line. Chief among these were intersystem cross talk and channel noise.

The smoothness of the attenuation characteristic of the line was also important, but it was decided to examine individual attenuation test results if necessary rather than to define a limit at the outset.

The limits for intersystem cross talk and channel noise are closely allied, since the former contributes to the total noise received on a channel. In this case, however, it was necessary to set limits on the single-frequency interpair cross-talk measurements made at frequencies in the *SOJ* range on individual repeater sections in order that lines might be prepared and proved suitable in advance of connecting the carrier equipment. For this purpose, the limit was first fixed for intelligible cross talk at voice frequencies and interpreted, by assuming certain advantages due to the use of staggered carrier frequencies, into limits for the measurements to be made on the lines at carrier frequencies.

For the final measurements of channel noise, a limit was set for the total noise. Part of this total was allotted to pure line noise and a calculation made to ensure in advance that, with the transposition systems, gage of wire, and repeater-station spacings proposed, the noise on channels picked up on the line would be within limits except perhaps under very abnormal weather conditions.

2.2 Intersystem Cross-Talk Limits

After examining the reports of the International Consulting Committee on Telephony in the matter and considering that the *SOJ* circuits were to form the main link between Rio de Janeiro and São Paulo, it was decided to aim at a figure of 59 decibels for over-all intelligible far-end cross talk between channels lined up to a net loss of 7 decibels.

Allowing for some cross talk in the equipment and voice-frequency entrance cables, taking into account the fact that the measurements on the line would be made as far-end cross-talk ratio,[3] and allowing for the advantages due to the use of the staggered channel frequencies of the four *SOJ* systems, the limits shown in Table 1 were tentatively set for the over-all high-frequency cross talk. For simplification and since strictly accurate treatment was not possible due, among other things, to the multiplicity of types of telephone sets in general use, only two different staggering advantages were assumed in the *A* to *B* direction instead of the normally accepted three.

It was decided to set the limit tentatively for high-frequency cross talk on each of the four individual repeater sections of the line at 6 decibels better than those shown in Table 1, on the assumption that each repeater section would contribute equally to the total cross talk. In practice, as described later, it was found that one repeater section was controlling and that nearly the whole over-all cross-talk limit could be allotted to it.

Several methods of analyzing the high-frequency cross-talk test results were tried out, but it was finally found best to use the simplest, namely to note the worst peaks and relate their values to the limits given in Table 1.

It was not proposed to use compandors on this project as there were none available.

2.3 Channel Noise Limits

A detailed examination of the information and recommendations available in 1946 regarding channel noise showed that the situation was by no means clear either as regards the desirable limit or with respect to the noise to be expected on open-wire lines in Brazil.

Sleet and ice conditions are never experienced on the line, so that the technical choice of repeater-section attenuation is dependent only on line noise.

Considering the importance of the *SOJ* circuits, it was decided to aim at a figure for the maximum total noise at a channel point of planning level 6 decibels below the transmitting toll switchboard of 27 decibels above reference noise (−90 decibels referred to 1 milliwatt at 1000 cycles per second); this figure corresponds approximately with 2.0 millivolts psophometric electromotive force as defined by the International Consulting Committee on Telephony.

TABLE 1

Tentative Limits on Over-All High-Frequency Cross Talk

Between Systems	Far-End Cross-Talk Ratio in Decibels	
	B–A 36–84 Kilocycles	*A–B* 92–143 Kilocycles
A and *B*	47	40
A and *C*	53	46
A and *D*	47	40
B and *C*	47	40
B and *D*	53	46
C and *D*	47	40

In practice, as will be seen in section 6.3, the noise measurements were made with a Western Electric *2-B* noise-measuring set using the *F-1-A* frequency weighting and expressed in "dba." Although the scale of dba (decibels adjusted) in this case uses a 1000-cycle reference point of −85 instead of −90 decibels referred to 1 milliwatt, the disturbing effect of noise measuring 0 dba using *F-1-A* weighting is considered approximately equivalent to that of noise measuring 0 decibel referred to −90 decibels referred to 1 milliwatt at 1000 cycles using *144* weighting (for which the −90 decibels referred to 1 milliwatt applies), when the noises are present in telephone networks using telephone sets for which the weighting networks are designed to apply.[4] In Brazil, the vast majority of telephone sets are not equivalent to that for which the *F-1-A* weighting is designed, but it was decided to use this weighting with a view to the future.

Inside this limit, it was decided to aim at a figure for the maximum contribution by pure line noise (i.e., atmospheric static, dust static, thermal agitation, etc.) of 23 decibels above reference noise, leaving the remainder of the noise (cross talk from other carrier systems, equipment noise, interchannel modulation noise,

[3] The expression "far-end cross-talk ratio" is used in this article to indicate that the far-end cross talk is measured by comparing the levels on the disturbing and disturbed circuits at points of equal planning level. It is sometimes referred to as "output-to-output cross talk" or "signal-to-cross-talk ratio."

[4] Report 45, Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System.

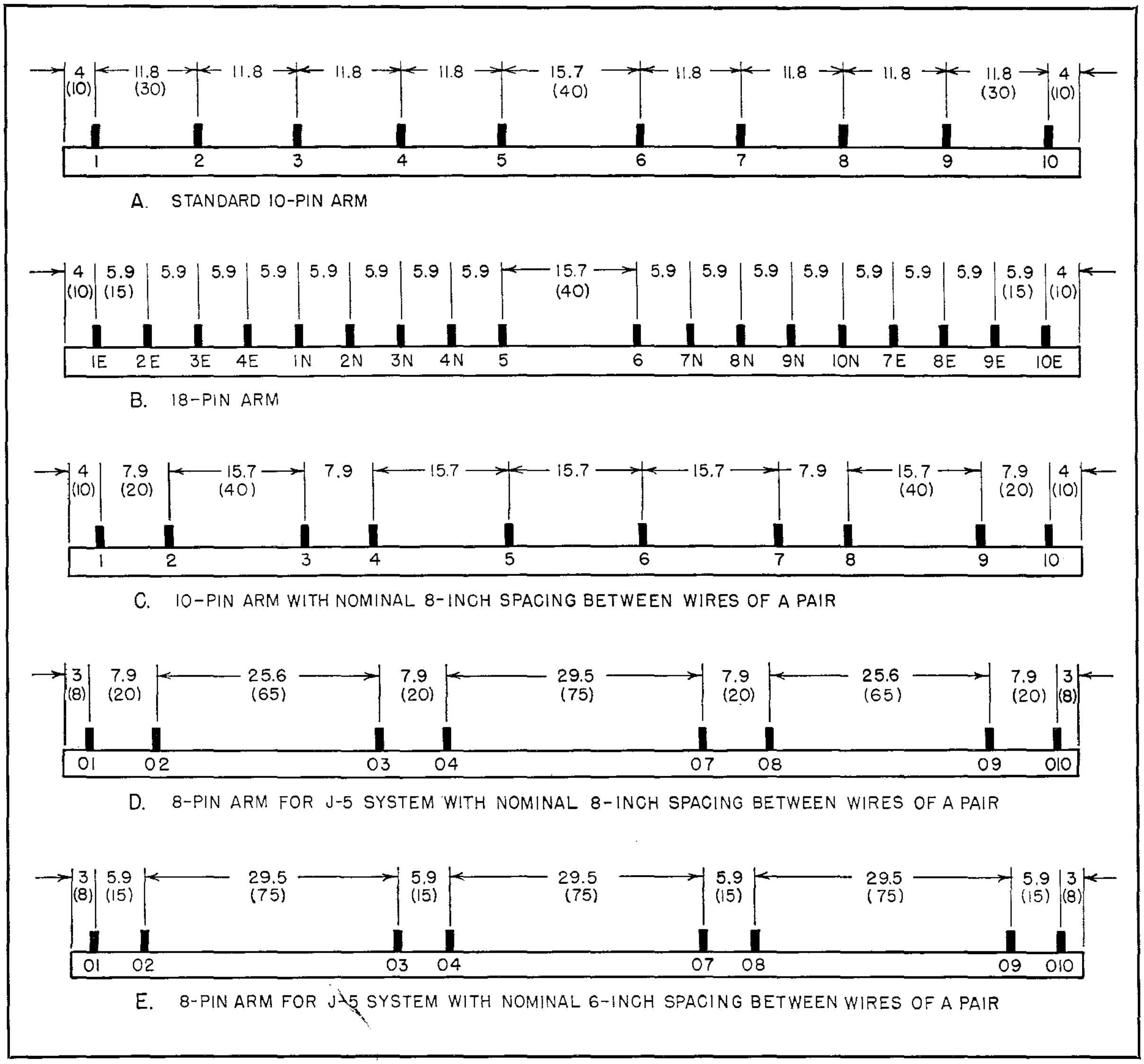


Figure 3—Crossarms and wire spacings. All dimensions are in inches with equivalents in representative places in (centimeters). All arms are approximately 9 feet 10 inches (3 meters) long. The pin numbers are for first or "zero" arms.

etc.) to contribute a maximum of about 25 decibels above reference noise.

Figures published by the Bell System[5] show that atmospheric line noise at 140 kilocycles in the United States would not generally exceed +10, +5, and −2 decibels with respect to reference noise on open-wire lines transposed to the alternate-arm, *K-8-2*, and *J-1* transposition systems, respectively. It was thought that the atmospheric line noise on the route between Rio de Janeiro and São Paulo would not be worse than that encountered in the United States.

Since, however, as described later, the majority of the *K-8-2* transposition sections between Nova Iguaçú and Km 117 would be longer than the maximum values for which they were designed, it was decided to assume a maximum atmospheric noise on this section of 9 decibels above reference noise. On each of the three repeater sections between Bananal and Tatuapé, which were to be transposed to the *J-5* system based on a long section of 7.8 miles (12.6 kilometers),

[5] L. M. Ilgenfritz, R. N. Hunter, and A. L. Whitman, "Line Problems in the Development of the Twelve-Channel Open-Wire Carrier System," *Bell System Technical Journal*, v. 18, pp. 363–387; April, 1939: page 379.

it was decided to assume a maximum atmospheric noise of 2 decibels above reference noise.

The question arose as to what figure to use for the line attenuation calculations, since the porcelain insulators used were believed to give better wet-weather attenuation results than the American double-petticoat alkaline-glass ones,

TABLE 2

Attenuation Figures Used for Noise Calculations

Type of Insulator	Spacing in Inches (Centimeters)	Attenuation in Decibels per Mile	
		Dry Weather	Wet Weather
Double-Petticoat Glass	7.9 (20)	0.306	0.418
Porcelain	5.9 (15)	0.314	0.425
Porcelain	7.9 (20)	0.306	0.418

and the latter appeared to give better results in practice than the normally quoted figures; also, it was believed that atmospheric noise was not generally at its worst during very wet weather.

After an examination of test results on old lines, the noise calculations were made for both wet- and dry-weather conditions, using the attenuation figures for 0.104-inch (2.642-millimeter) copper wire at 140 kilocycles given in Table 2.

On this basis, the atmospheric line noise in Nova Iguaçú at a point 6 decibels below the São Paulo toll switchboard was found by calculation to be 20.2 and 11.3 decibels above reference noise for wet- and dry-weather conditions, respectively. Since both these figures are inside the limit, the use of 0.104-inch (2.642-millimeter) copper wire with the proposed transposition systems and repeater-station spacings appeared to be satisfactory from a channel noise viewpoint.

3. *Details of Relevant Lines Existing in 1946*

3.1 Nova Iguaçú to Km 117

This section of the line was constructed in about 1938 with wooden and steel (tram rail) poles supporting wooden crossarms generally spaced at 2 feet (0.6 meter). The wire was 0.104-inch (2.642-millimeter) copper strung on alkaline-glass double-petticoat insulators on the first three crossarms and on toll procelain insulators on the other crossarms. Wooden pins were used except on transposition brackets and no bonding was attempted. The first four crossarms were 10-pin types and the fifth arm was generally 18-pin. On the first arm, the spacing between wires on a pair was 7.9 inches (20 centimeters) (Figure 3C). On the second, third, and fourth arms, the spacing was 11.8 inches (30 centimeters) (Figure 3A), except for about 15 miles (24 kilometers), where the spacing on the third arm was the same as on the first arm. On the fifth arm, the spacing between wires of a pair was 5.9 inches (15 centimeters) (Figure 3B).

There were only 10 through pairs between Nova Iguaçú and Km 117, the majority of the other pairs dropping off in the first 21 miles (34 kilometers) from Nova Iguaçú.

The line was transposed in accordance with the *K-8* system on an 8-span basis, the nonphantomed types being used on the four nonpole pairs of the first arm and the phantomed types being used on all other groups. There were 7 *KA*, 3 *KB*, 5 *KC*, 3 *KD*, and 1 *KE* sections and the sum of the squares of the transposition pole-spacing deviations (feet squared) was less than 0.1 times the length (feet) of this section of line. However, for about 87 percent of the line, the lengths of the transposition sections were about 20 percent greater than the maxima for which they were designed.

Except for one place where two phantom groups left the line near the middle of a transposition section, the wires generally left the line at *S* poles. Point-type transposition brackets were used on the nonpole pairs of the first arm and drop type on all the other groups.

3.2 Cachoeira Paulista to Tatuapé

This section of the line was originally constructed in about 1918. It has been subjected to almost continuous change ever since, both with regard to its route, which is constantly being modified due mainly to road movements, and also with regard to the number of wires equipped and transposition arrangements used due to the need for increasing the number of circuits. Poles were mainly wooden with a few steel (tram rail) and cement ones and mounted wooden crossarms spaced generally at 2 feet (0.6 meter). The wires were 0.104-inch (2.642-millimeter) copper strung on alkaline-glass double-petticoat insulators and toll porcelain insulators. Wooden pins were used except on transposition brackets and no bonding was attempted.

The line was equipped with five toll crossarms with, in some places, an additional arm or two for toll and subscribers circuits. The first three arms were standard 10-pin type with 11.8-inch (30-centimeter) wire spacing (Figure 3A). The fifth arm was an 18-pin type with 5.9-inch (15-centimeter) wire spacing (Figure 3B). The fourth arm was similar to the first three except for about 36 miles (58 kilometers) between Caçapava and Tatuapé, where it was similar to the fifth arm.

The line was transposed in accordance with the alternate-arm (phantomed) system on an 8-span basis. As can be seen from Figure 4, the transposition arrangements were complicated by the use of 18-pin arms. Between Cachoeira Paulista and Caçapava there were 5 long-*A*, 2 short-*A*, 2 short-*L*, and 1 short-*2R* sections (excluding an incomplete section at the Cachoeira end); the sum of the squares of the transposition pole-spacing deviations (feet squared) for the alternate-arm transposed pairs was approximately 2.73 times the length (feet) of the line. Between Caçapava and Tatuapé, there were 9 long-*A* and 3 short-*L* sections, with the sum of the squares of the deviations at approximately 2.93 times the length.

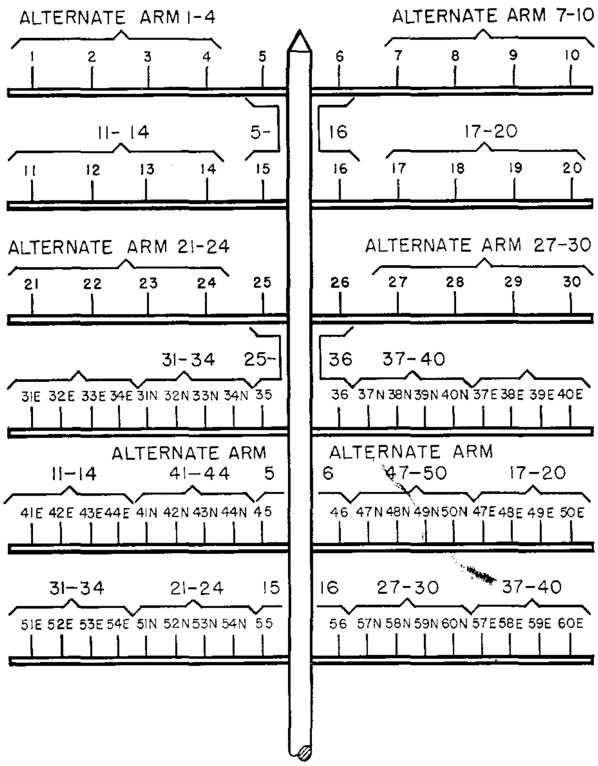


Figure 4—Typical transposition types for the line between Caçapava and Tatuapé in 1947. The pin numbers are above the pins. Transposition types are indicated by brackets. Transposition sections are unexposed line *A* and exposed line *L* and *R* except where otherwise indicated. Pins 31E–34E and 37E–40E have pin types 31–34 and 37–40 of exposed-line *E* section and 61–64 and 67–70 of exposed-line *L* section. The complicated transposition arrangement made necessary by the use of 18-pin crossarms is evident as also is the corresponding increase in the number of toll-circuit facilities obtained by their use.

Pairs leaving the line from the first three crossarms left it at *S* poles; from the other arms pairs left from non-*S* poles in several places.

Point-type transposition brackets were used for the alternate-arm-transposed side circuits and for the side circuits of one phantom group on the fourth crossarm for about 28 miles (45 kilometers); otherwise drop-type brackets were used.

4. *Preliminary Measurements*

It was thought that it might be found possible to operate the *SOJ* systems over existing pairs, perhaps without retransposition, except for the section between Km 117 and Cachoeira Paulista, where a new line was to be constructed. Certain preliminary tests were therefore made early in 1947 and are briefly reviewed below.

4.1 Tests Between Nova Iguaçú and Km 117

Attenuation and impedance measurements were made in March, 1947, on the four non-phantomed pairs on the first crossarm and on two other pairs between Nova Iguaçú and Barra Mansa [11 miles (18 kilometers) beyond Km 117]. Further tests were made in June between Nova Iguaçú and Km 117 in both directions and included extensive attenuation, near-end cross-talk, far-end cross-talk, and impedance (made as return-loss) measurements. The attenuation results corresponded almost exactly with those made in March.

On pairs 1–2, 3–4, and 7–8, only slight absorption peaks were found over the frequency range up to 143 kilocycles, which never exceeded about 0.02 decibel per mile and were generally much less. On pair 9–10, however, an absorption peak of about 0.1 decibel per mile was found between about 130 and 146 kilocycles. On pairs in phantom groups 11–14 and 21–24, a continuous series of absorption peaks was found above about 30 kilocycles, which never exceeded about 0.07 decibel per mile. Typical attenuation results are shown in Figure 5.

An analysis of the cross-talk results showed quite clearly that not more than two *SOJ* systems could be operated within limits over this section of the route as it was in 1947. Typical cross-talk results are shown in Figure 6.

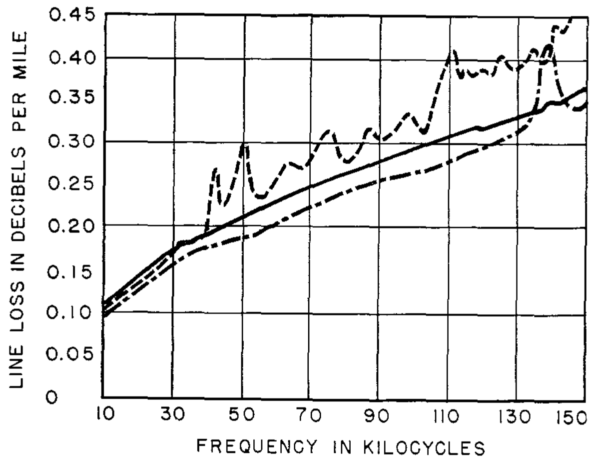


Figure 5—Typical loss curves for the line between Km 117 and Nova Iguaçú in June, 1947, with *K-8* transpositions. The solid line is for pair 7–8 in cool misty weather, dash-dot for pair 9–10 in hot dry weather, and dashed curve for pair 11–12 in cool misty weather. The absorption peak on pair 9–10 was removed later. It is evident that pair 11–12 is quite unsuited for 12-channel carrier operation.

4.2 Tests Between Cachoeira Paulista and Tatuapé

Attenuation and impedance measurements were made in March, 1947, on the Cachoeira Paulista-to-Caçapava and Caçapava-to-Tatuapé sections. Since there was no *S* pole at Cachoeira Paulista, some of the tests were repeated from the nearest accessible *S* pole [about 9.5 miles (15 kilometers) nearer Caçapava]; the shapes of the attenuation curves were found to be almost identical with those made from Cachoeira Paulista. Typical results are shown in Figure 7.

An examination of the results showed that most of the alternate-arm-transposed pairs would be suitable from an attenuation smoothness viewpoint for the operation of an *SOJ* system on a manual-gain-control basis, with the loss of not more than three channels. Since all these pairs showed large absorption peaks between about 85 and 98 kilocycles, the successful operation of the automatic-pilot-control system in the *A–B* direction seemed doubtful as one of the pilot frequencies was located at 92 kilocycles.

From the cross-talk viewpoint, the operation of more than one *SOJ* system seemed doubtful. Certainly more than two systems could not be expected to operate within the cross-talk limits.

A point of interest was that on the section of the line between Cachoeira Paulista and Caçapava, one of the 5.9-inch-spaced (15-centimeter) pairs on an 18-pin arm (fifth) gave a noticeably smoother attenuation curve than any other pair.

5. Preparing and Testing the Line

5.1 General

The preliminary measurements summarized above showed quite clearly that the sections of the existing line proposed for operation of the four *SOJ* systems were quite unsuitable for that purpose as they stood in 1947.

One *SOJ* system could have been operated on a manual-gain-control basis, but since the possibility of installing and testing the necessary

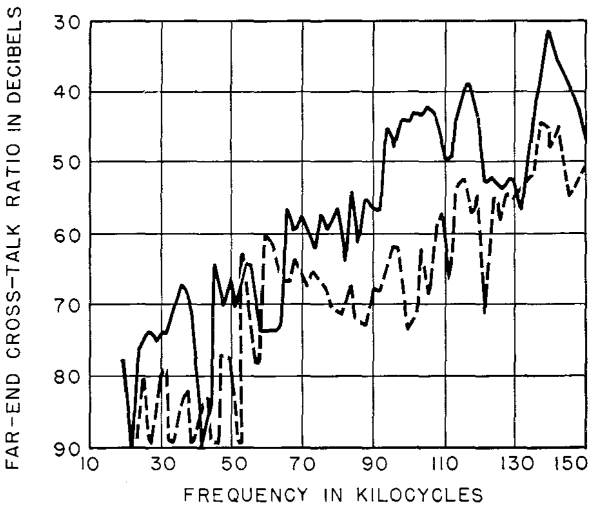


Figure 6—Typical far-end cross-talk-ratio curves for the 62 miles (100 kilometers) between Km 117 and Nova Iguaçú in June, 1948, with *K-8* unphantomed transpositions. The solid line is for pair 7–8 disturbing and 9–10 disturbed while the dashed line is for pair 1–2 disturbing and 7–8 disturbed.

SOJ equipment before the line could be prepared for the operation of all four systems seemed remote, it was decided to push ahead with the final preparation of the line and to avoid wasting time preparing for interim operation of a single system.

5.2 Nova Iguaçu to Bananal

The tests had shown that on the part of the line between Nova Iguaçú and Km 117, transposed to the *K-8* system, not only was the cross talk outside limits but also a serious absorption peak was present on pair 9–10. The *K-8-2* system is designed for easy retransposition of pairs already transposed to the *K-8* system and generally will provide satisfactory operation of an *SOJ* system on every outside pair (i.e., 1–2, 9–10, 11–12, 19–20, etc.), and on each of pairs 7–8 and 33–34.

In this case, however, many of the transposition sections were longer than their design lengths, a fact that might account for the absorption peak on pair 9–10, and the absorption peak might not disappear on retransposition to the *K-8-2* system. It might also be necessary to retranspose phantom group 17–19 to the *K-8-2* system in order to remove the peak.

Retransposition to the *J-5* or the *LJ* (Standard Telephones and Cables) system was considered since they are based on a longer transposition section. A pole-spacing analysis showed that, although the spacing of the poles for the triple extra transposition points was very uniform, that of the intermediate poles was very irregular and more than 200 poles would have to be moved to correct it. Since in the *LJ* system and for the second-arm arrangement of the *J-5* system transpositions have to be located on these intermediate poles and also as the retransposition work involved would be extensive with consequent dislocation of the existing circuits and high expense, it was decided to begin by retransposing the nonpole pairs of the first crossarm to the *K-8-2* system and test them. In the meantime, advantage was taken of the necessity to move part of the line due to road reconstruction and thus shorten some of the transposition sections.

The new piece of line between Km 117 and Bananal was constructed using 0.104-inch (2.642-millimeter) copper wires with 7.9-inch (20-centimeter) spacing between the wires of a pair (Figure 3D). The line was transposed to the *J-5* transposition system and consisted of two *J-5AA* sections. Tests made in 1948 showed that the attenuation curves were quite smooth and

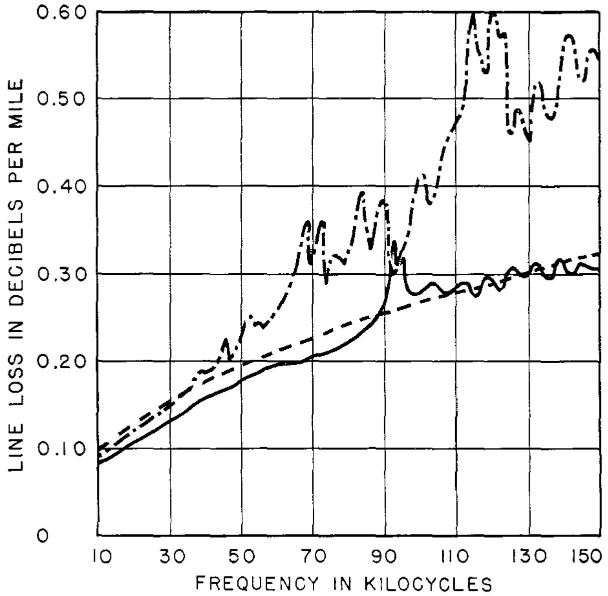


Figure 7—Loss curves typical of the line between Caçapava and Cachoeira Paulista. Measurements for the solid line, pair 1–2 (alternate-arm transposed) and the dash-dot line for pair 13–14 (exposed and unexposed lines transposed) were made in 1947 and those for the dashed curve, pair 01–02 (*J-5* transposed), were made in 1949. The absorption peak between about 85 and 98 kilocycles on pair 1–2 is typical of the alternate-arm-transposed pairs and would probably prevent the proper operation of the 92-kilocycle pilot control of any *SOJ* system connected over such a pair.

that at no point up to 143 kilocycles was the far-end cross-talk ratio worse than 61 decibels for all permutations of the four pairs; it was generally much better. This small piece of line was therefore considered quite satisfactory and would contribute negligible cross talk when connected to the piece between Nova Iguaçú and Km 117.

Tests made later on the whole repeater section after the top arm had been retransposed to the *K-8-2* system showed that the absorption peak on pair 9–10 had disappeared. The tests of far-end cross-talk ratio (described in Section 6.2), including lead-in cables at each end, between all permutations of *SOJ* pairs in the *A–B* direction showed no peaks worse than 40 decibels between adjacent pairs, 41 decibels between alternate pairs, and 48 decibels between outside pairs.

These results and others made earlier showed quite clearly that this section of the line was outside the tentative cross-talk limit for individual repeater sections, of 6 decibels better than those given in Table 1 for the whole line. Plans were therefore made for additional retransposition work. However, since the cross-talk results for the whole line could be within the limits if the rest of the line was found to contribute negligible cross talk to the total or even if the peaks of cross talk occurred at different frequencies from those on this section, the retransposition work was deferred, pending the cross-talk results for the rest of the line being available.

In practice, as described in 6.2, it was later found to be unnecessary to do any further retransposition work on this section of the line.

5.3 Bananal to Cachoeira Paulista

This new piece of line was constructed similarly to the piece between Km 117 and Bananal using 0.104-inch (2.642-millimeter) copper wires with 7.9-inch (20-centimeter) spacing between the wires of a pair (see Figure 3D), transposed to the *J-5* system first-arm arrangement. In addition to the four *SOJ* pairs, two pairs for voice-frequency use had to be strung, and the same pole route had to be used to lead about eight toll pairs and a few subscribers pairs from the *SOJ* repeater station (where they were to pick up interaction cross-talk-suppression arrangements) to the town of Cachoeira Paulista, a distance of about half a mile.

The two voice-frequency pairs were transposed to the exposed-line nonphantomed transposition system and equipped on a crossarm spaced 6 feet (1.8 meters) below the top arm, thus leaving room for a further *SOJ* arm if required later.

There were eight complete *J-5AA* sections between Bananal and Cachoeira Paulista, seven being 7.93 miles (12.9 kilometers) long and one about 7.75 miles (12.5 kilometers).

For the first seven sections from Bananal, seven exposed-line *E* sections were coordinated with the *J-5AA* sections, i.e., the *S* poles coincided and the average transposition interval of one system was equal to or an even multiple of that of the other system (in this case one was four times the other). For the last sections, one exposed-line *E* and three *R* sections were applied with the *J-5AA* section on an uncoordinated basis, i.e., not more than one *S* pole of any section of one transposition system coincided with an *S* pole of the other transposition system and the average interval (or an even multiple of it) of one system was different by more than 10 percent from that of the other; an *S* pole between two *R* sections was located at the point where the wires left the line for the town of Cachoeira Paulista.

The sum of the squares of the transposition pole-spacing deviations (feet squared) for the *J-5* first-, third-, and fourth-arm arrangements was less than 0.13 times the length (feet) of this section, being well inside the limit of 0.33. For the second-arm arrangement, for which quintuple extra transposition points have to be established, the corresponding figure was 0.40, which could be brought inside the limit by installation of a special pole at one place.

Since this construction and transposition system were new in Brazil and since a great deal depended on their success both on this section of the line and on others, it was decided to make preliminary measurements as soon as possible. This was done when the first four transposition sections out of Cachoeira Paulista had been completed. The tests, which included attenuation, far-end cross talk, near-end cross talk, and impedance (return loss), were made between Cachoeira Paulista and *S4*, which was an isolated pole situated at the top of a hill known locally as "Morro Frio" (cold hill). A photograph, shown on page 276, which was taken during these tests, illustrates the spacing of the crossarms referred to earlier and the type of terrain through which the line passes.

Later, when the whole repeater section had been completed, some of the tests were repeated between Cachoeira Paulista and Bananal. These tests showed the same general characteristics as those made earlier from *S4*, the far-end cross-talk-ratio peaks generally being up to 3 or 4 decibels worse.

On the whole repeater section, an analysis of the far-end cross-talk-ratio peaks on all permutations of the four *SOJ* pairs measured from each end of the line showed no peaks worse than those given in Table 3.

A more detailed analysis showed that this repeater section was well within the limits set in Section 2.2. Typical cross-talk results are shown in Figure 8.

TABLE 3

FAR-END CROSS-TALK-RATIO PEAKS BETWEEN CACHOEIRA PAULISTA AND *S4*

Between Pairs	Cross-Talk-Ratio Peaks in Decibels	
	36–84 Kilocycles	92–143 Kilocycles
Adjacent	61	54
Alternate	70	54
Outside	80	68

The attenuation curves for the *SOJ* pairs were absolutely smooth (within the limit of the accuracy of the measuring methods employed). The attenuation curves for the other pairs showed that they were quite unsuitable for *SOJ* operation, having absorption peaks as large as 0.26 decibel per mile.

The return-loss measurements on *SOJ* pairs (made with pure resistances) were found to be best when the line was terminated at the far end in 600 ohms and its impedance compared with 600 ohms, in which case all *SOJ* pairs gave a return loss between 5 and 150 kilocycles of better than 28 decibels.

A point of interest was that during the measurements a transposition error was suspected since a comparison with the results obtained at *S4* indicated that those being made at Bananal were worse than they should have been. On further inspection of the line, an error was found at the *J-5AA/88* point on the third section from Bananal, a transposition having been installed on pair 7–8 instead of 3–4. When this had been rectified, the measurements were repeated and the results appeared to be noticeably better.

5.4 Cachoeira Paulista to Tatuapé

Many different schemes were proposed and discussed for obtaining four pairs suitable for *SOJ* operation over the two repeater sections between Cachoeira Paulista and Tatuapé; it was finally decided to add an extension arm (to be known as the "zero" arm) 3 feet (0.9 meter) above the existing first arm, and equip on it four 0.104-inch (2.642-millimeter) copper pairs spaced at 29.5 inches (75 centimeters) with 5.9 inches (15 centimeters) between wires of a pair (see Figure 3E) and transposed to the *J-5* system first-arm pin types. This arrangement of crossarms is clearly shown in Figure 14.

It would be impossible to enumerate here all the arguments put forward for and against this arrangement, but among the more important considerations were the following.

A. The scheme should cause a minimum of dislocation to the already badly overloaded circuits between Rio de Janeiro and São Paulo.

B. No *SOJ* systems were likely to be ready for operation in sufficient time to replace any circuits taken off traffic for retransposition work.

C. A new line, which might prove economical, would not be practicable at this time since the existing road between Rio de Janeiro and São Paulo was due for replacement by a new one whose route had not yet been chosen.

D. A great number of poles would have to be moved if the *J-5* second-arm arrangement was chosen.

A survey of the line was made to determine the construction work involved in erecting the

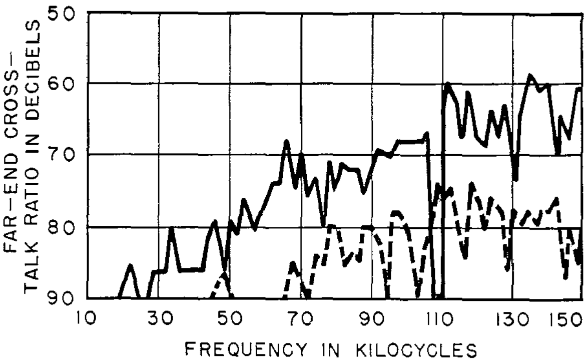


Figure 8—Typical far-end cross-talk-ratio curves for line between Cachoeira Paulista and Bananal (*J-5* transposed), a distance of 65 miles (105 kilometers). The solid line is for pair 1–2 disturbing and 3–4 disturbed. The broken line is for pair 1–2 disturbing and 9–10 disturbed.

zero arm. It showed that, apart from fitting insulators and transposition brackets and stringing the wires, approximately 4500 extension arms had to be erected, 1200 crossarms had to be lowered and 100 poles had to be substituted.

The detailed plan for transposing the four pairs on the zero arm was then made. In general, *J-5AA* sections were coordinated with alternate-arm long-A sections and the J-5 shorter sections were, where the pole spacing permitted, applied on an uncoordinated basis with the alternate-arm shorter sections.

It was necessary, mainly for the sake of economy, to move as few poles as possible. A systematic analysis of the pole spacing was therefore made from the existing pole records and calculations made to improve the transposition pole-spacing deviations by moving about 250 poles to their theoretically optimum positions, as well as relocating a few of the 100 poles mentioned above that had to be substituted. Surveys were then made in the field to ascertain to what extent these theoretical moves could be made in practice.

TABLE 4

DETAILS OF TRANSPOSITION SECTIONS BETWEEN CACHOEIRA PAULISTA AND CAÇAPAVA, 1949

Alternate-Arm Transposition System			J-5 Transposition System								
Section			Section			1st, 3rd and 5th Arms			2nd Arm		
Number	Type	Length in Feet	Number	Type	Length in Feet	Average Interval in Feet	Σu^2 in Feet Squared	$\frac{\Sigma u^2}{L}$	Average Interval in Feet	Σu^2 in Feet Squared	$\frac{\Sigma u^2}{L}$
1	Part of Long A	8,140	1.1 1.2 1.3	F E D	720 2,570 5,200	89.8 160.3 162.6	310 6,730 4,840	0.44 0.26 0.93	89.8 160.3 162.6	310 6,730 4,840	0.44 0.26 0.93
2	Long A	41,400	2	AA	41,400	323.4	28,870	0.70	161.7	237,900	5.76
3	Long A	41,300	3	AA	41,300	323.0	35,000	0.85	161.5	299,800	7.27
4	Long A	41,800	4	AA	41,800	327.0	48,600	1.15	163.5	165,700	3.97
5	Short L	15,160	5.1 5.2	C D	10,120 5,040	158.2 157.5	840 1,430	0.08 0.28	158.2 157.5	840 1,430	0.08 0.28
6	Short A	34,140	6.1 6.2	A C	22,800 11,340	178.3 177.2	900 400	0.04 0.04	178.3 177.2	900 400	0.04 0.04
7	Long A	41,700	7	AA	41,700	326.0	50,750	1.22	163.0	99,500	2.39
8	Short A	33,570	8.1 8.2 8.3	F A C	1,390 22,340 9,840	173.9 174.5 153.7	10 1,950 32,600	0.01 0.09 3.31	173.9 174.5 153.7	10 1,950 32,600	0.01 0.09 3.31
9	2R	4,060	9	D	4,060	127.0	3,100	0.76	127.0	3,100	0.76
10	Long A	41,500	10	AA	41,500	324.3	38,400	0.93	162.1	131,700	3.17
11	Short L	16,330	11.1 11.2	C D	10,870 5,460	169.5 170.8	63,100 24,600	6.35 4.51	155.7 170.8	63,100 24,600	6.35 4.51
					319,450		342,430	1.07		1,075,410	3.37

The results of the surveys were examined in detail and it was found possible, by moving just under 200 poles (excluding those that had to be substituted), to reduce the sum of the squares of the transposition pole-spacing deviations (feet squared) for the repeater sections Cachoeira Paulista to Caçapava and Caçapava to Tatuapé from about 2.85 and 3.45 times the repeater section lengths (feet) to about 1.07 and 1.35, respectively.

Later, the figure for the section between Caçapava and Tatuapé was further reduced to about 1.20 by the installation of a span-type transposition arrangement described in Section 5.6 on the four *SOJ* pairs in two places where a river and a gully, respectively, prevented the location of poles.

Details of the arrangement of the transposition sections are given in Table 4 for the section from Cachoeira Paulista to Caçapava. From this table, it will be seen that there are five *J-5AA* sections coordinated with alternate-arm long-*A* sections and one *J-5D* coordinated with an alternate-arm *2R* section, the remainder of the sections, except the first three, being applied on an uncoordinated basis. The first section, a *J-5F*, runs on a spur line of four spans from the terminal pole in Cachoeira Paulista to the existing line, which it joins near the *X* transposition point of the alternate-arm long-*A* section (13/16 of the section), and thence runs for four spans on the existing line. The *J-5E* and *J-5D* sections, which follow it, are not applied on an uncoordinated basis with the remainder of the alternate-arm section, since their average transposition intervals are almost exactly half that of the long-*A* section.

It will be seen also that all transposition sections are within their design lengths except for four *J-5AA* sections (which are all less than 1.5 percent too long) and three shorter sections, which are between 3.5 and 8 percent too long. Table 4 also emphasizes the difficulty that would be experienced if septuple extra transposition points were to be established on the *J-5AA* sections in the event of applying the second-arm transposition arrangement.

For the section from Caçapava to Tatuapé, there are nine *J-5AA* sections coordinated with alternate-arm long-*A* sections, one *J-5B* coordinated with a short-*L*, and one *J-5C* coordinated with a short-*L*. A *J-5C* and a *J-5D* are applied with a short-L on an uncoordinated basis. All the *J-5AA* sections are longer than their designed length, the worst being 1.65 percent too long, and all the short sections are within their design lengths. The difficulty in applying the *J-5* second-arm arrangement would be even greater for this repeater section than for the other, since the sum of the squares of the pole-spacing deviations would be about 5.3 times the length of the section.

On each repeater section, there were a few cases where spans greater than 230 feet (70 meters) were unavoidable. The spacing between wires of *SOJ* pairs was increased to 11.8 inches (30 centimeters) for these long spans only.

In selecting *S*-pole transpositions, all transposition sections of the same type within a main *SOJ* repeater section were considered as a series, regardless of the number of transposition sections of other types separating them.

Attenuation, far-end cross-talk, near-end cross-talk, and return-loss measurements were made on the *SOJ* pairs from each end of the repeater sections from Cachoeira Paulista to Caçapava and from Caçapava to Tatuapé in December, 1948, and January, 1949, respectively.

TABLE 5

FAR-END CROSS-TALK-RATIO PEAKS

Between Places	Between Pairs	Cross-Talk-Ratio Peaks in Decibels	
		36–84 Kilocycles	92–143 Kilocycles
Cachoeira and Caçapava	Adjacent Alternate Outside	66 69 71	58 59 65
Caçapava and Tatuapé	Adjacent Alternate Outside	66 68 76	57 58 66

Analyses of the far-end cross-talk-ratio curves on all permutations of the four *SOJ* pairs measured from each end of the repeater sections showed no peaks worse than those given in Table 5.

A more detailed analysis showed that these repeater sections were well within the limits set in Section 2.2.

Typical cross-talk results for the section from Caçapava to Tatuapé are shown in Figure 9.

The attenuation curves showed no absorption peaks greater than 0.003 decibel per mile. A typical result is shown in Figure 7. The return-loss measurements (made with pure resistances) were

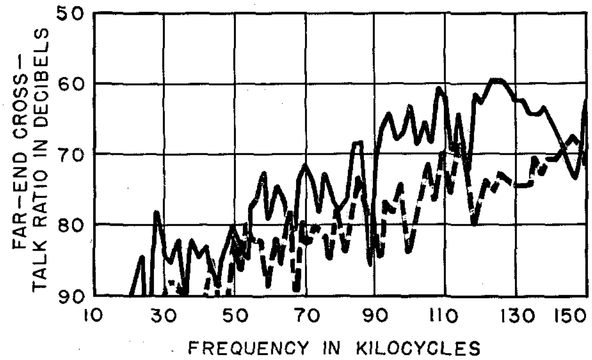


Figure 9—Typical far-end cross-talk-ratio curves for the *J-5*-transposed circuits between Caçapava and Tatuapé, a distance of 79 miles (127 kilometers). The solid line is for pair 7–8 disturbing and 3–4 disturbed. The broken line is for pair 9–10 disturbing and 1–2 disturbed.

best when the line was terminated at the far end in 550 ohms and its impedance compared with 550 ohms, in which case all pairs gave a return loss between 5 and 150 kilocycles of better than 29 decibels.

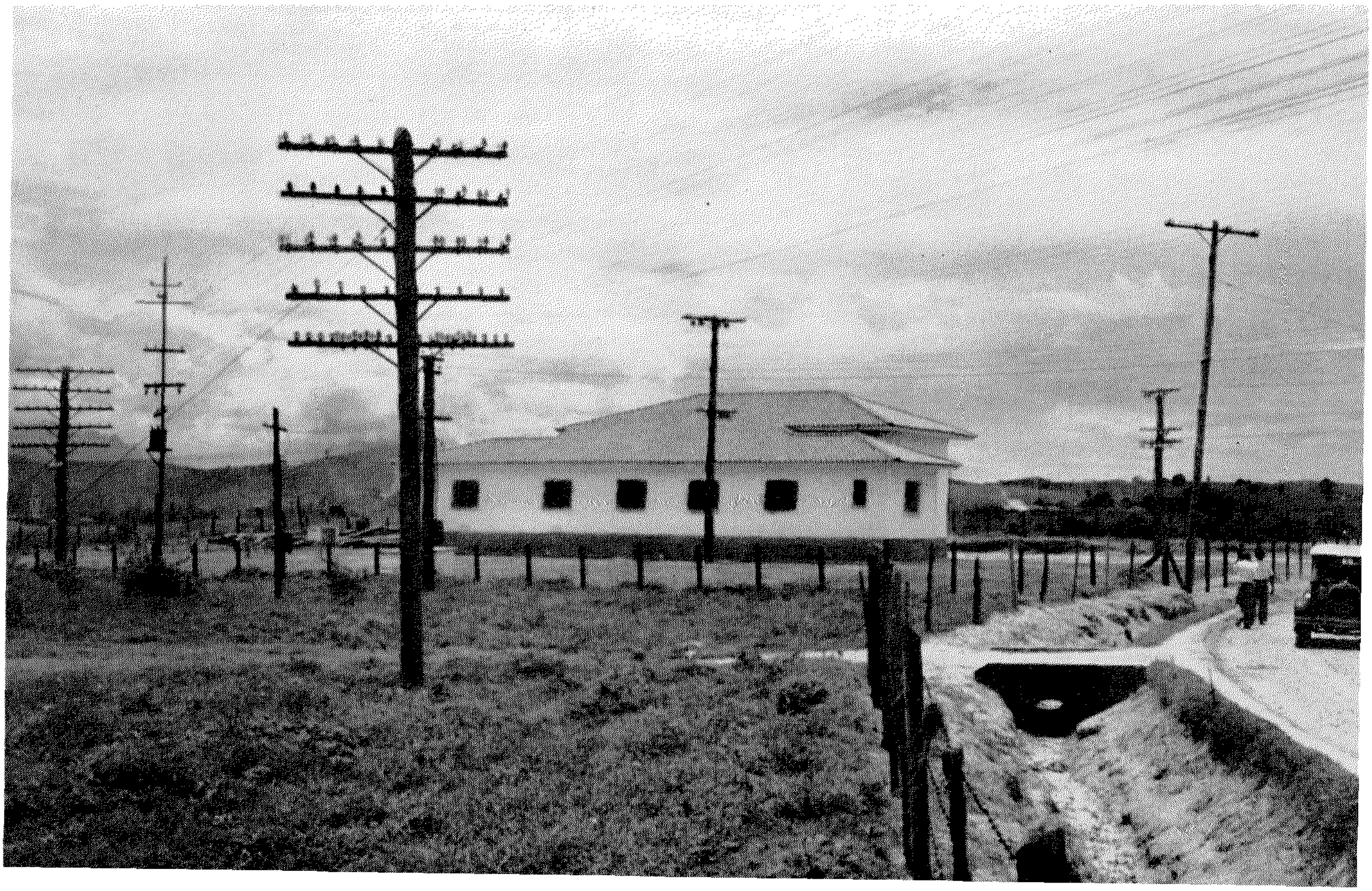
Further tests were made later between Caçapava and Tatuapé to confirm that cross talk between the zero arm and the first, third, and fifth arms was satisfactory at *C* frequencies. The results showed no far-end cross-talk-ratio measurements with the zero arm worse than 60 decibels up to 30 kilocycles, and the vast majority much better. They also showed that a pair could be chosen with satisfactory cross talk to the zero arm for operation of an additional suitably staggered *SOJ* system on a manual-gain-control basis.

5.5 Interaction Cross-Talk Suppression

In this type of 12-channel carrier system, in which there is no frequency translation at repeater stations, quite low couplings between *SOJ* pairs and other pairs or the longitudinal of the line may cause high cross talk or even singing around a repeater station. As described elsewhere,[6] this is controlled by cutting a gap in the

[6] See pages 376 and 377 of reference 5.

Figure 10—Cachoeira Paulista repeater station. The "old" line to Barra Mansa is on the left with its new spur line from the Caçapava side terminating on the pole (shown up close in Figure 11) beside the building in the center of the picture. The terminal pole on the Bananal side is to the right in the background. The "gap" between the terminal poles on either side of the station can be seen clearly.



line in front of the repeater station, installing cross-talk-suppression filters on non-*SOJ* circuits passing through the station, and installing longitudinal choke coils on all circuits entering the station.

In the cases of Bananal and Cachoeira Paulista, the suppression was quite simple and standard, since few circuits were involved and the necessary gap was easily established. In the latter case, since it was not desirable to lead in the circuits of the existing line passing on to Barra Mansa, a project to connect the town of Cachoeira Paulista direct to a point on the line to Barra Mansa instead of passing through the repeater station was dropped since interaction cross-talk paths would be established around the triangle so formed. Details are illustrated in the photographs in Figures 10 and 11.

The case of Caçapava was far more complicated. A gap had already been established of about 55 feet (16.8 meters). The existing toll circuits entered the station from the terminal poles on either side of this gap, running in separate cables to the toll distributing frame.

The existing subscribers circuits were taken off from poles about 1400 feet (427 meters) away (Rio de Janeiro side) and 2400 feet (732 meters) away (São Paulo side), where they entered cables that were strung on the pole route to the two terminal poles outside the station, whence they entered a cable chamber in separate cables. These cables were spliced into cables common to all subscribers and thus ran to a main frame in the switchboard room. On the Rio de Janeiro side, there were 14 subscribers pairs on the open-wire line, the longest running on it for about 4 miles (6.4 kilometers); on the São Paulo side there were 8, the longest running for about 6 miles (9.7 kilometers).

A condition was thus possible whereby an open-wire-line subscriber on one side being connected through to one on the other side of the station, the gap would be effectively bridged. There were some toll circuits also that passed directly through the station without voice-frequency repeaters as well as some passing through repeatered. In addition, tests made on the existing 3-channel carrier repeaters showed that the attenuation through them in the *B–A* direction was quite low even at 140 kilocycles (in some cases only about 10 decibels).

Figure 11—Terminal pole on the Caçapava side of the Cachoeira Paulista repeater station. The circuits on the lower crossarm enter the station to connect to interaction cross-talk-suppression filters. The boxes on the crossarms contain carbon arresters and longitudinal choke coils to assist in suppressing interaction cross talk around the station.

The voice-frequency repeaters were all equipped with low-pass filters, but the coupling in the wiring backwards and forwards between the toll test board, repeating coils, etc. was an unknown factor. The following suppression plan was therefore adopted.

A. The gap of about 55 feet (16.8 meters) was maintained.

B. Longitudinal choke coils were installed in all open-wire toll and subscribers circuits on both sides of the station.

C. All open-wire circuits from the Rio de Janeiro side of the station were connected to cross-talk-suppression arrangements before coupling was possible with other circuits. In the case of 3-channel carrier repeaters, "roof" filters were connected in the *B–A* direction and the jumpers on the toll distributing frame on the *B* side were run in screened pairs. In the case of all through nonrepeatered circuits, through repeatered circuits on the first 4 crossarms, terminated circuits from the Rio de Janeiro side, and open-wire subscribers' circuits on the Rio de Janeiro side, 12-kilocycle cross-talk-suppression filters were equipped and connected by screened jumpers on the Rio de Janeiro side.

D. For leading in the subscribers circuits on the Rio de Janeiro side, a new 26-pair cable was spliced in to lead the open-wire circuits concerned direct to the toll distributing frame.

As described later, these arrangements appear to have been successful in eliminating interaction cross talk.

5.6 Line-Construction Details

In general, the Companhia Telephonica Brasileira aims at attaining International Telephone and Telegraph System standards of line construction, and most of the dimensions of the open-wire pole-route-line materials are based on those of that organization, modified to fit in with the metric system.

Figure 12—Typical crossarms, insulators, and transposition brackets. The zero crossarm carries 5.9-inch (15-centimeter) spaced wires on type-*2* porcelain insulators mounted on *H-15*-type transposition brackets. The first crossarm supports wires with 11.8-inch (30-centimeter) spacings; they are carried on double-petticoat alkaline-glass insulators mounted on both point- and drop-type transposition brackets.

The standard crossarm for toll circuits until the late thirties was the 3-meter (about 9-foot 10-inch) type with 30-centimeter (about 11.8-inch) spacing between wires as shown in Figure 3A. Later, this crossarm was modified to give 20 centimeters (about 7.9 inches) between wires

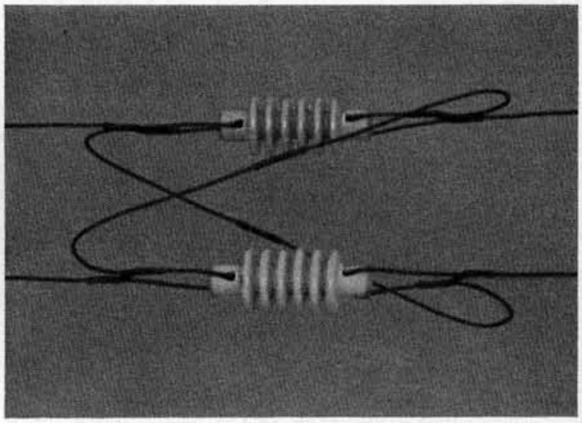


Figure 13—Special suspended-type transposition arrangement used to a limited extent on very long spans.

for use on carrier transposed pairs, as shown in Figure 3C and the 18-pin crossarm shown in Figure 3B was introduced on some routes to increase their circuit-carrying capacities. For the *SOJ* project, the 8-pin crossarms shown in Figure 3D and 3E were introduced to give 20-centimeter (about 7.9-inch) and 15-centimeter (about 5.9-inch) wire spacings. The crossarms are almost invariably wooden. Typical crossarms are shown in Figure 12.

Drop-type transposition brackets are generally used on voice-frequency transposed wires and point-type on carrier transposed wires. The point-type was, previous to 1947, made up of two separate plates each mounting two pins with insulators and kinked so as to give the necessary wire clearance at the point of crossover. For the *SOJ* project two *H* types were developed for the 7.9-inch (20-centimeter) and 5.9-inch

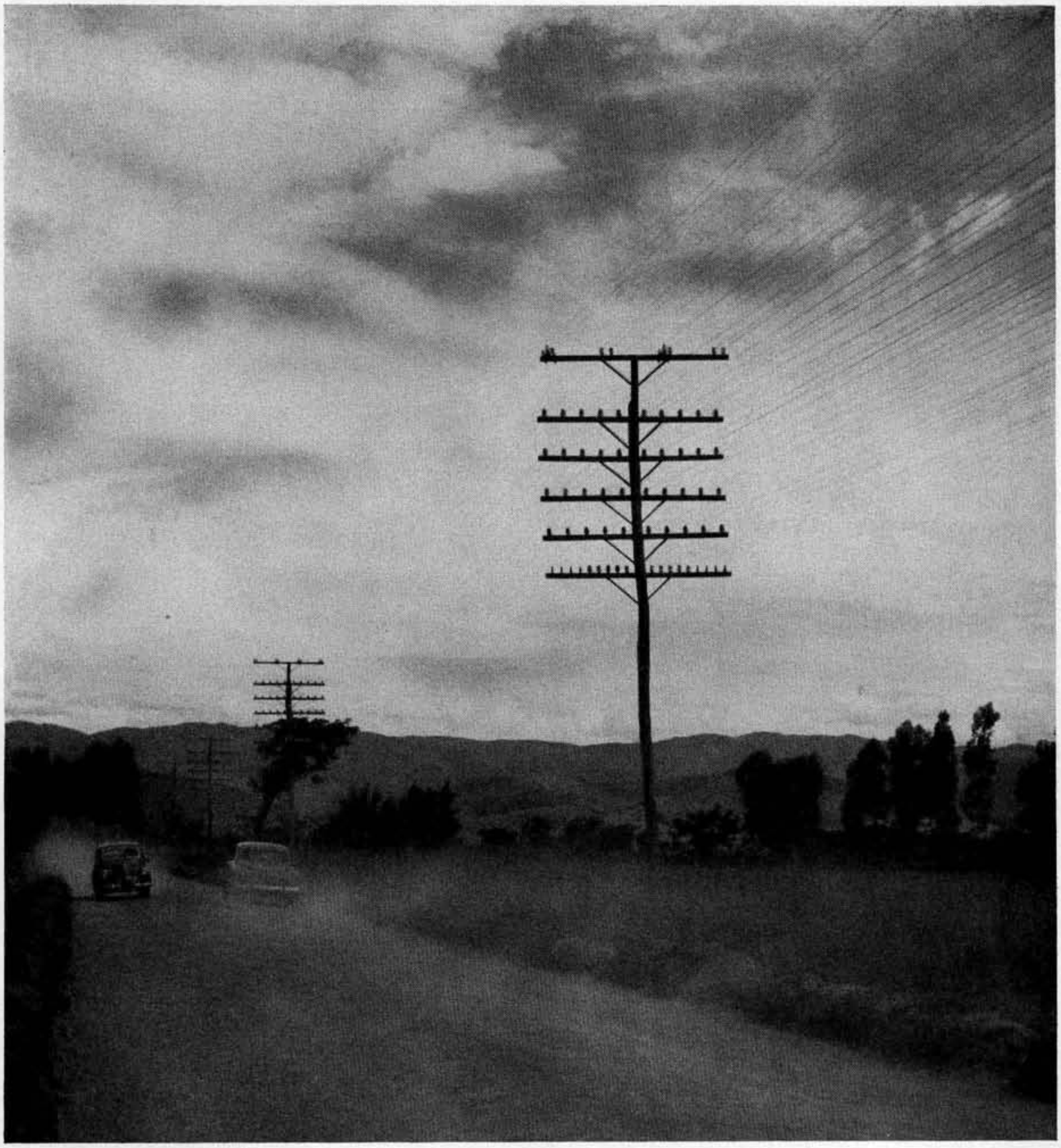


Figure 14—A few poles in the line between Cachoeira Paulista and Caçapava. The typical dusty road conditions are evident.

(15-centimeter) wire spacings, respectively. Several types are shown in Figure 12.

In two places, it was impossible to locate poles on which to install transpositions and, since by so doing a great improvement could be effected in the transposition-point-spacing deviations (as described in Section 5.4 above), it was decided to install a suspended type of transposition arrangement shown in Figure 13. This was to be installed on the *SOJ* pairs only, since the pole-spacing-deviation limits for the other pairs would be met in any case. For this purpose, a special insulator was designed about $4\frac{3}{4}$ inches (12 centimeters) long by about 1 inch (2.5 centimeters) basic diameter with holes through which to pass the wires and 6 concentric ribs 2 inches (5 centimeters) in diameter. The wires from each side were terminated on a pair of these insulators and jumpers connected to make the crossover, as shown in Figure 13. Since these were only

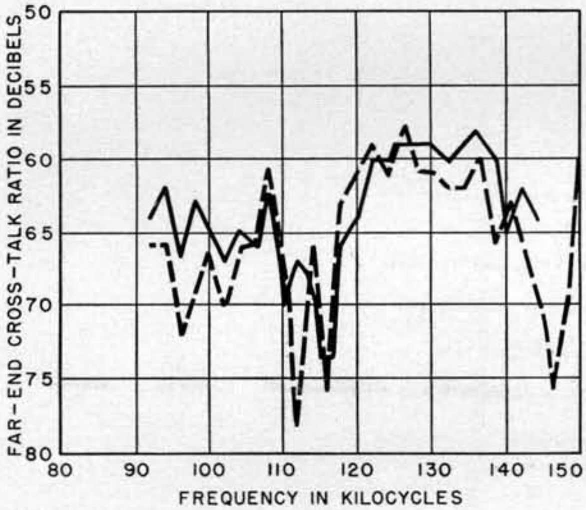


Figure 15—Typical comparison of far-end cross-talk ratio with (solid line) and without (broken line) lead-in cables. These values are for the section between Tatuapé and Caçapava for pair 03–04 disturbing and 01–02 disturbed.

required to be used in exceptional cases (two on this project), the leakage was not considered of great importance and the installation costs would be negligible.

Double-petticoat alkaline-glass insulators imported from the United States have been used on toll circuits extensively in the past, but Brazilian porcelain is reputed to be among the best in the world and the type-*2* porcelain insulator developed in Brazil is now standard for the Company's toll circuits. Both types are shown in Figure 12.

The vast majority of the poles used are of Aroeira wood—the hardest of the hard Brazilian woods. These poles often are not straight, but, despite this, the cross-arm spacing and symmetry of arrangement obtained in practice is as good as is generally obtained with poles that are quite straight. In towns, cement or steel (tram-rail) poles are generally used.

The *SOJ* open-wire pairs are in every case led in from the terminal poles direct to the line filter bays by means of low-capacitance cotopa-spaced paper-insulated quads of the *T.C.S. 314* type supplied by Standard Telephones and Cables, Limited. Protection is provided on the poles in the same box as the longitudinal choke coils and consists of the *26/30*-type carbon arresters (breakdown voltage around 750). On the line filter bays, *26/27*-type carbon arresters (breakdown voltage around 350) are supplied, which are followed by variable-resistance elements called "Metrosil discs," which have a low resistance when high voltages are applied across them.

Variable loading units are provided on the line-filter end of the lead-in cables; these were adjusted to give the optimum impedance match at the junction of cable with open-wire line when measured as a return loss.

6. Over-All Cross-Talk and Noise Results

6.1 General

An inspection of the cross-talk results on individual repeater sections indicated that *SOJ* systems types *A*, *B*, *C*, and *D* would give the best intersystem cross talk if operated over the whole length of the line on pairs 1–2 (01–02), 3–4 (03–04), 7–8 (07–08), and 9–10 (09–010), respectively. They were accordingly so connected for the final tests.

By August 1949, the line-up had been completed on most of the channels of three systems and on the high-frequency side of all four systems in the *A–B* direction. The circuits were urgently required for traffic, but, before they were handed over, certain cross-talk and noise tests were made to ascertain to what extent the planning had been effective.

Later, when a total of 45 channels had been lined up, more extensive cross-talk and noise measurements were made at nighttime.

The main object of these tests was, of course, to confirm as far as possible that the cross talk and noise on the channels at all normal times was such that the high quality of transmission provided by the *SOJ* channels in other respects was not impaired. Secondary objectives were:

A. To ascertain to what extent the tentative high-frequency line cross-talk limits given in Table 1 correlated with the intersystem cross talk when measured as noise on the channels.

B. To confirm that the lead-in arrangements properly matched the impedance of the equipment to that of the open-wire line.

C. To confirm that the interaction cross-talk suppression at repeater stations was effective.

D. To observe in what way the cross talk on repeater sections added up in practice.

E. To obtain information regarding the pure line noise.

6.2 High-Frequency Cross Talk

The carrier-frequency line cross-talk measurements included the lead-in cables, line filters, and, in the case of Nova Iguaçú, the entrance cable with its associated matching arrangements. Far-end cross-talk measurements were first made in the *A–B* direction on each repeater section and then on two or more repeater sections with

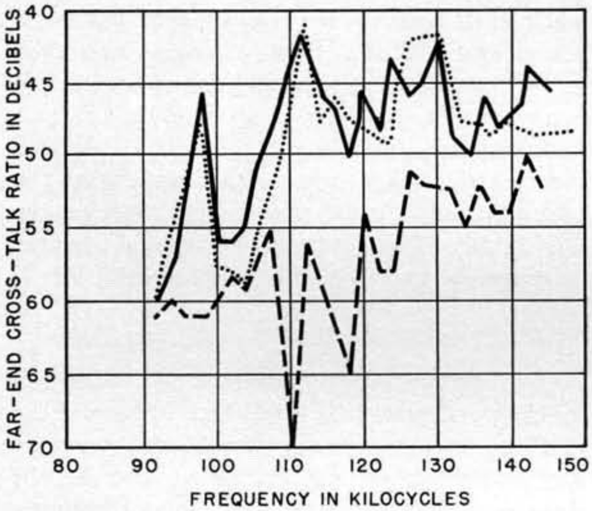


Figure 16—The over-all far-end cross-talk ratios for the complete circuit from Tatuapé to Nova Iguaçú are shown by the solid line. The broken line is for the Tatuapé–Bananal section. The remaining section from Bananal to Nova Iguaçú, shown dotted, comprises about a quarter of the total circuit length but contributes dominantly to the cross talk. Measurements were made with repeaters lined up for pairs 03–04 (3–4) disturbing and 01–02 (1–2) disturbed.

repeaters properly lined up, but operating on a manual-gain-control basis, between Tatuapé and Cachoeira Paulista, Bananal, and Nova Iguaçú, in turn.

Later, the over-all measurements between Tatuapé and Nova Iguaçú were repeated and similar measurements were made in the *B–A* direction.

The results of the measurements made on each repeater section were plotted on the same paper as those obtained nearly a year earlier on the open-wire only (except for the Bananal–Nova

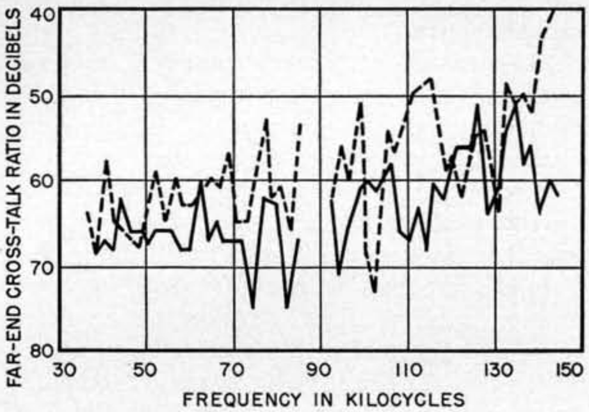


Figure 17—Typical over-all high-frequency cross-talk ratios with repeaters lined up for the Tatuapé–Nova Iguaçú circuit. The solid line is for system *A* disturbing and *D* disturbed. The broken line, for *B* disturbing and *C* disturbed.

Iguaçú section for which no previous test results were available). The curves were generally about the same shape and the peaks seldom differed by more than 2 or 3 decibels. A typical result is shown in Figure 15.

These results were regarded as practical proof that the impedance matching of lead-in cable with open-wire line had been made satisfactorily.

Analyses of the results of the other measurements led to the following conclusions.

A. In general, the cross talk appeared to add up as the sum of the powers present, although there were notable exceptions. No cases were found in which the sum was more than 6 decibels worse than either component and few in which it was more than 2 or 3 decibels worse.

B. The repeater section between Bananal and Nova Iguaçú was undoubtedly the controlling factor in the over-all cross talk in every case. This is well illustrated in Figure 16, which is a typical result.

C. Interaction cross talk was negligible at repeater stations under the conditions of the tests.

Figure 17 shows typical over-all high-frequency cross-talk results between Tatuapé and Nova Iguaçú. An analysis of results is given in

Table 6, from which it will be seen that, with one exception, they are within the limits tentatively set in Section 2.2. Many of them are just on the limit so that the method of interpretation of the results and the exact staggering advantages assumed are found to tip the balance between a fair proportion of the results being within or outside the limits.

The results of interchannel cross-talk and noise tests and of listening tests made on the worst channels at heavy-traffic times are of course the final criteria and are dealt with later.

It was gratifying to find that, despite all the fears of conflicts and the effect of pole-spacing irregularities between Cachoeira Paulista and Tatuapé, the sum of the cross talk for three repeater sections when measured between Tatuapé and Bananal with repeaters lined up was well within the tentative limits set in Section 2.2 for a single repeater section. In fact, it was so well within limits that the Bananal-to-Nova Iguaçú section could be allowed to contribute practically all the over-all high-frequency cross talk and thus, although it was outside the limits set for a single section, the over-all cross talk was within the tentative limit.

6.3 Interchannel Cross Talk and Noise

These measurements were made between Nova Iguaçú and Tatuapé with all channels lined up to 3.5 ± 0.5 decibels loss between the 2-wire points; with this line up, the system levels were approximately the same as for the final line up between Rio de Janeiro and São Paulo with the entrances to the two cities connected on a 4-wire basis. The tests included A) channel noise, B) within-system interchannel cross talk, and C) intersystem interchannel cross talk.

TABLE 6

Over-All Far-End Cross-Talk Ratio Between Tatuapé and Nova Iguaçú with Repeaters Lined Up

Combination of *SOJ* Systems	Maximum Peaks in Decibels			
	Results		Limits	
	B–A	*A–B*	*B–A*	*A–B*
A and *B*	50	40	47	40
A and *C*	62	47	53	46
A and *D*	60	51	47	40
B and *C*	53	40	47	40
B and *D*	55	45	53	46
C and *D*	55	44	47	40

6.3.1 *Channel Noise*

The channel noise measurements were made at the same time as the intersystem measurements with all channels of the four systems properly terminated and with no disturbers connected. The measurements were made with a Western Electric *2-B* Noise-Measuring Set using *F-1-A* weighting and the results expressed in decibels adjusted (dba).

To prove that the line noise is within limits, a prolonged series of measurements under all types of weather conditions is necessary, and this has not yet been done. However, under the conditions prevalent during several series of tests, including very heavy dew, which on this line appears to correspond approximately with wet weather as far as line attenuation is concerned, many channels in both directions measured better than 18 dba. Some channels measured worse, due apparently to noise introduced in the equipment in Tatuapé, a trouble that is still under investigation.

Thus, so far as tests have been made up to the present, channel noise arising from noise on the line is quite satisfactory. Some typical channel noise results are included in column 3 of Table 7.

6.3.2 *Within-System Interchannel Cross Talk*

The within-system interchannel cross-talk measurements were made on three systems in the *A–B* direction by speaking on 11 channels of a system and measuring at the far-end on the remaining channel with a *2-B* Noise-Measuring Set. The results showed that this type of cross talk was negligible and no further measurements of it were made.

6.3.3 *Intersystem Interchannel Cross Talk*

To measure the intersystem cross talk in such a way that other channel noise had a negligible masking effect, the conditions for these tests were purposely made considerably more severe than those under which the channels would be used in practice.

All channels on all four systems were terminated at the 2-wire point in 600 ohms at both ends; the *2-B* Noise-Measuring Set was connected to the disturbed channel in place of the termination at one end and the noise measured on the channel without any disturbers. Magneto-type telephone sets equipped with Western Electric *F-2A* capsules were then connected at the other end in place of the terminations on all channels whose frequency bands overlapped that of the disturbed channel. The speakers disturbed first on one system at a time and then on all three systems at the same time. They were male voices adjusted so that a Western Electric volume meter[7] indicated about +4 volume units on peaks when bridged across the circuits.

Having decided to establish these test conditions the difficulty arose as to how the results could be related to the practical case of traffic on the circuits.

Several factors had to be taken into account. Among the more important were the relation between the circuit levels during the tests and in the final line-up and the relation between a number of disturbers speaking at a fairly constant volume of +4 volume units and the conditions to be expected in practice with two-way conversations between subscribers with voices, loops, and telephones that might be very different from those of the test. After consideration of these and other factors, it was decided that the conditions could be considered to be approximately 13 decibels more severe than the worst that would be encountered in practice. It was therefore decided to regard cross talk as outside limits when it gave rise during these tests to channel noise worse than 38 decibels adjusted.

The results showed that on the 45 channels tested all channels in both directions were within this limit, except for channel 3 of system *D* in the *A–B* direction, which measured 39 dba; in addition, it was not possible to measure cross talk within limits on 4 channels owing to noise introduced in Tatuapé being worse than 38 dba.

To illustrate the relation between the high-frequency cross talk on the line and the intersystem cross talk on the channels, Table 7 has been prepared for all channels in the *A–B* direction into which cross talk introduced noise that measured worse than 33 dba.

[7] The type of volume indicator used is calibrated to indicate 0 volume units when it is bridged across a 600-ohm circuit with 1000 cycles at 0 decibels relative to 1 milliwatt.

TABLE 7

INTERSYSTEM CROSS TALK IN *A–B* DIRECTION SHOWING RESULTS ON WORST CHANNELS

Disturbed		Measured Channel Noise in dba						Approximate High-Frequency Line Cross Talk in Decibels from System			
		Without Disturbers	With Disturbers on Systems								
System	Channel		*A*	*B*	*C*	*D*	All 3	*A*	*B*	*C*	*D*
A	1	18	–	32	26	22	35	–	(40) 43–44	(46) 52–53	(40) 58–66
	2	17	–	24	30	21	38	–	44–45	55–62	52–53
	3	17	–	36	25	21	37	–	42–43	59–60	57–58
	4	15	–	35	24	19	36	–	44–45	56–60	58–62
	7	17	–	32	32	21	34	–	43–44	52–55	56–63
	8	18	–	37	28	18	37	–	43–44	52–54	61–63
B	1	15	26	–	19	27	34	(40) 42–46	–	(40) 53–57	(46) 52–57
	3	19	32	–	30	27	34	49–50	–	46–48	52–57
	5	15	27	–	26	34	35	44–60	–	53–57	52–56
	6	15	30	–	26	36	37	40–46	–	49–50	52–55
	7	28	35	–	29	32	37	40–42	–	54–56	51–58
	9	15	26	–	19	32	34	45–47	–	47–54	50–55
C	4	15	28	27	–	24	36	(46) 56–59	(40) 56–58	–	(40) 44–52
D	3	22	27	37	28	–	39	(40) 52–59	(46) 45–49	(40) 46–47	–
	4	19	22	35	20	–	35	55–64	47–50	46–47	–
	5	20	24	34	21	–	36	53–57	50–60	47–53	–
	8	22	22	28	22	–	35	63–67	47–57	52–55	–

Note: Figures in parenthesis are the limits set in Section 2.2.

In examining Table 7, it is advisable to bear in mind how difficult it is to control accurately the sending volume in cross-talk tests of this type. One can picture a hot repeater station in the early hours of the morning; five telephones are arranged round a table with their speakers. On a word from the controller, two men lift their receivers and speak into the microphones, the controller urging them to regulate their outputs according to the readings on the volume indicator that he can connect across any circuit. On advice from the far-end, another pair speak, then one speaks alone, and then all five speak together. In the meantime, coffee has been prepared and, in the next series of measurements, voices can be expected to be louder.

It is surprising, in the circumstances, to find on examining Table 7 that it is generally from precisely those channels where the high-frequency line cross talk is nearest the limit that a channel receives noise nearest the 38 dba limit. An examination of the table indicates that the channels with the 46-decibel high-frequency cross-talk limit tend to disturb a little more than would be expected, but, on the whole, the line cross-talk limits appear to be about correct.

The fact that the only channel outside limits corresponded with the only high-frequency result outside limits is interesting but can only be regarded as a general trend rather than positive proof of a rigid relationship between the two sets of measurements. In another series of these tests in which many results were so near the limits for both high-frequency cross talk and channel noise and the test conditions were so difficult to control, other channel combinations might be found to be just outside limits.

The real criterion, of course, is whether or not the cross talk is of such a magnitude that it interferes unduly with the exchange of information over the channels by means of speech. Some listening tests were made that indicated that, even during the busy hour, the cross talk did not appreciably interfere with speech, although it could be clearly heard.

However, it would be wise to expect the cross-talk condition effectively to worsen as the general toll service improves and the subscribers become more critical and hence more easily annoyed by cross talk and also as the operating methods and facilities improve so that more conversations are in progress simultaneously on the channels.

7. Conclusions

A. The construction and transposition of the open-wire line are such that intersystem cross talk is at a satisfactorily low level for the present conditions.

B. This result was reached only by obtaining a superior performance on more than three quarters of the line to permit the remainder to contribute nearly all the over-all cross talk.

C. Conclusive evidence has not yet been obtained that the repeater-station spacing, gage of wire, and transposition systems employed give satisfactory channel noise derived from pure line noise under all normal weather conditions. However, the tests detailed here and others not mentioned indicated that this part of the planning also had been satisfactory.

D. The test results obtained on the 140 miles (225 kilometers) of line on which the extension arm was erected showed that a very satisfactory performance had been obtained.

E. The use of human speakers in multiple-disturber cross-talk tests in which the measurements are made in terms of noise is not very satisfactory. Some means of producing artificial speech from 11 outputs with the necessary random distribution is very desirable for this type of work.

F. The application of four additional *SOJ* systems to the line can be expected to present some interesting problems. Between Km 117 and Cachoeira Paulista, the installation of the second arm will provide a simple solution. Between Cachoeira Paulista and Tatuapé, it may prove economical to construct a new line along the new road that is now nearing completion; on the other hand, it may be decided to retranspose the existing second crossarm [5 feet (1.5 meters) below the zero arm] to the *J-5* second- or third-arm arrangement. Between Nova Iguaçú and Km 117, the solution of the problem will depend to some extent on whether or not it is decided again to allow this part of the line to contribute nearly all the total cross talk. The use of compandors will also have to be considered when applying further *SOJ* systems to the line.

G. In tackling a problem of the type outlined in this article, the engineer has to choose constantly between a costly plan that will certainly give the required technical result and one that may give a borderline result but which will save a great deal of money if successful. He has to remember that the whole object of the project is to provide the additional toll service economically, a fact that in practice he is unlikely to be allowed to forget for long. Retransposing or stringing new wire and relocating poles is a costly business, but, if the engineer departs from standard practice, as he must do in a case like this, and if he relaxes on the normal limits, then he will know whether or not his planning has been successful only when the tests are made on completion of the work; if it has not been successful, then the whole program may be upset and the final result far more costly than would have been the case if the right plan had been followed in the first place. The proper presentation of a technical plan to nontechnical commercial and financial staff and an understanding of their problems, the successful solution of which keeps the company in business, become essential parts of the engineer's job in this type of work.

H. Experience plays an important part in finding an economical solution to this type of problem.

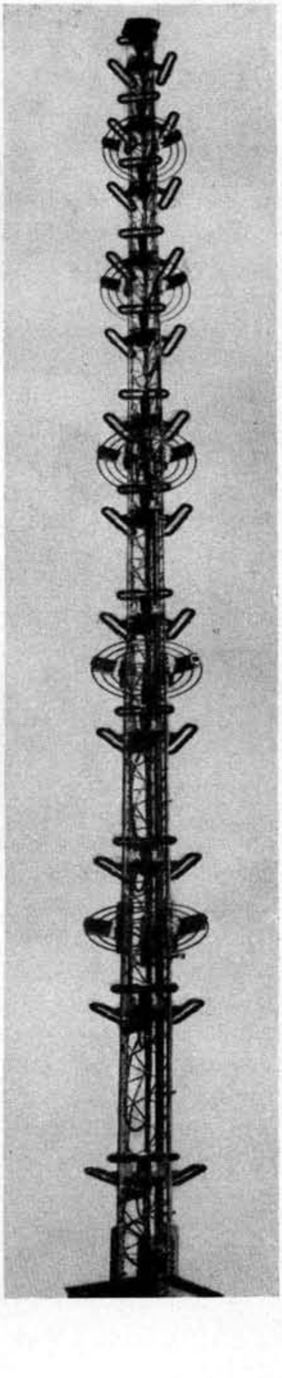
8. Acknowledgments

The author expresses his appreciation to all those who assisted both directly and indirectly in the production of this article, to Mr. L. H. Armstrong, Transmission Engineer of the Companhia Telephonica Brasileira, for his advice and encouragement and to his colleagues Messrs. A. W. Ewen, G. H. Foot, P. F. Webb, I. Kristiansen, J. Padlas Jr., C. Romeu, and many others who collaborated in the work on which the article is based.

Recent Telecommunication Development

Television Transmitting Antenna for 174–216-Megacycle Band

TELEVISION BROADCASTING, utilizing dominantly line-of-sight propagation for its primary coverage, requires a transmitting antenna producing in the horizontal plane a uniform circular distribution of radiation and in the vertical plane a highly concentrated pattern aimed toward the horizon.



The antenna shown consists of 12 triangular loops or bays. Each loop, consisting of three folded dipoles, can safely handle a kilowatt of power and radiates both the visual and aural signals.

The 12-bay antenna has a power gain of 11.8, equivalent to 10.7 decibels, over that of a half-wave dipole in the direction of the horizon. Up to 16 bays can be used to give power gains of 15.4 (11.9 decibels) and produce fields of effective radiated powers exceeding 240 kilowatts.

The same tower structure can be used for any channel in the television broadcasting band extending from 174 to 216 megacycles per second.

In Buenos Aires, an 8-bay antenna and 5-kilowatt transmitter built by Federal Telecommunication Laboratories produces the highest effective radiated power (45 kilowatts) of any television station in the Americas.

Determination of the Piezoelectric Constants of Some Isomorphous Crystals*

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QUANTITATIVE investigation of the piezoelectric activity of crystals, especially of those that may be artificially grown from organic or inorganic substances, has made but small progress since the fundamental research done by Voigt, Riecke, Pockels, and their pupils. Only quartz and Rochelle salt were repeatedly investigated with respect to their technical characteristics.

The click method of Giebe and Scheibe has been valuable for testing qualitatively the piezoelectric activity of crystalline substances and has allowed rough conclusions to be drawn with respect to the intensity of the effect. With the help of this method, many substances have been investigated, especially by Hettich, in a search for materials having piezoelectric properties. A number of substances having strong piezoelectric activity have been found. Later, quantitative determination was made of the piezoelectric effects of such organic compounds as rhamnose, hexamethylene tetramine, and asparagine by Meyer and Gockel.

This paper is concerned with a continuation of this search for substances having a positive Giebe–Scheibe effect and the determination of the piezoelectric constants of those that show this effect to a high degree. The search for suitable substances having strong piezoelectric effects is well justified by the fact that quartz and Rochelle salt crystals, used hitherto exclusively for technical purposes, are not adequate for all possible applications.

Extensive investigations of similar substances and a comparison of the findings is of aid in understanding the electrophysical properties of crystals. Only a few investigations of a quantitative character have been carried out in this direction. Valesk observed the temperature relation of the piezo effect of sodium bromate and has compared the results with the behavior of sodium chlorate, while Mandell investigated ammonium Rochelle salt in view of the strong piezo effect of sodium potassium tartrate.

By the Giebe-Scheibe method, substances having large piezoelectric effects may be identified. As a result of such preliminary tests, the primary phosphates of potassium and ammonium, nickel sulphate hexahydrate, lithium sulphate, potassium tartrate, ammonium tartrate, ammonium oxalate, strontium formate, and barium formate appeared promising. Likewise the isomorphous substances, sodium chlorate and sodium bromate, as well as heptahydrates of zinc sulphate, magnesium sulphate, and nickel sulphate appeared promising.

1. Growing of Crystals

The chief difficulty that had to be overcome was the manufacture of suitable specimens of the selected substances. Attempts to grow suitable crystals of ammonium oxalate, strontium formate, and barium formate did not lead to satisfactory results although the Giebe–Schiebe effect looked promising at least for the first two compounds. In the case of the other substances, the growing of crystals was accomplished by cooling or evaporating the solvent from a saturated aqueous solution in which a seed was placed. The growth was effected in equipment of the type described by Moore and Schwartz.

The temperature of crystallization was between 30 and 40 degrees centigrade except for the crystallization of nickel sulphate. The crystallization of rhombic nickel sulphate was effected at 20 degrees centigrade as this form is produced only below 30 degrees. After some preliminary tests to determine suitable growing conditions, the growth of the following crystals was successfully accomplished: $NaBrO_3$, KH_2PO_4, $NH_4H_2PO_4$, $NiSO_4+6H_2O$, $NiSO_4+7H_2O$, $ZnSO_4+7H_2O$, $MgSO_4+7H_2O$, and $C_4H_4O_6K_2+\frac{1}{2}H_2O$. Greater difficulty was experienced in growing suitable lithium sulphate

* This is a translation of part of an unpublished thesis accepted by the University of Göttingen in 1938.

and ammonium tartrate crystals. Lithium sulphate grows in plate form in the plane of $s(\bar{1}01)$ while ammonium tartrate shows prisms elongated in the b axis and thin vertically to a (100). For investigation purposes, the thickness of the crystals has to be at least 10 millimeters. Therefore, the conditions had to be changed in such a manner as to get thicker crystals.

Following a proposal of Johnson, the seeds were fixed in a plane perpendicular to the b axis and rotated slowly in the solution.

Even seeds that were suspended vertically with respect to a or c and were left to themselves grew to become crystals of a considerable thickness by evaporation of the solvent. In this way, a lithium sulphate crystal was grown that reached 16 millimeters perpendicular to $(\bar{1}01)$ while an ammonium tartrate crystal grew to 19 millimeters perpendicular to a.

2. *Processing of Crystals*

The determination of the characteristic piezoelectric modulus requires the preparation of crystals in the form of rectangular parallelopipeds of certain orientation with respect to the crystallographic axis. To achieve a high degree of accuracy, the optical method of orientation of the crystal was used instead of the contact method. For this purpose, a reflection and a grinding goniometer, both capable of operating in azimuth and height were used. A well-grown crystal having good reflecting surfaces was glued on a support. The reflection goniometer is adjusted to suitably plane surfaces with known indices thus providing a basis for the calculation of those planes that have to be produced by grinding. Subsequently, the crystal support is transferred to the grinding goniometer and, after having set the calculated values of azimuth and height on both graduated dials, the limiting planes of the parallelopiped, which are perpendicular to each other, may be ground. The finishing is done by parallel grinding by hand on a tripod similar to the parallel grinder of Fues. The orientation of the reference system (x, y, z) corresponds to the crystallographic main axis (a, b, c). In agreement with Voigt, Holman, and others, the twofold polar axis of monoclinic crystals coincides however with the z axis of the coordinate system.

3. *Measurement of Piezoelectric Constants*

The determination of the piezoelectric modulus consists in the measurement of that quantity of electricity that is generated by a known pressure on crystals of a given orientation. When the capacitance of the set-up is known, this measurement is reduced to the determination of the voltage to which this capacitance is brought by the quantity of electricity that is produced by the pressure.

To carry out this task, several methods may be used. However, the accuracy of the measurement may be impaired because of inadequate insulation. In principle, a loss of charge through insufficient insulation may be avoided by preventing any voltage drop from occurring between the electrodes of the crystal. Such a method has the advantage that the crystal is under well-defined conditions with respect to electric voltage stresses, since the field that arises through piezoelectric polarization is balanced by another field and the crystal is in an electrically neutral state during measurement.

If a crystal is subjected to a constant mechanical stress, it seems to be possible to determine the piezoelectric voltage by compensation. However, it must be noted that the adjustment of compensation forces requires time and is practicable only if a small voltage drop is admitted for the purpose of effecting a balance. Each voltage drop however, results in a loss of charge although it is small if the time constant of the whole system is large.

To avoid this source of loss, the mechanical stress should be a periodic function of time, thus causing the piezoelectric crystal to work as an alternating-voltage generator. If an alternating voltage of the same shape and opposite phase is applied to the piezoelectrically excited crystal, it may be kept continuously in an electrically neutral state. Each charge produced by the alternating pressure in the crystal is balanced or compensated instantaneously by an equal charge of opposite sign from outside. Equilibrium is effected by keeping a voltage indicator, which is in parallel to the crystal, continuously at zero. The execution of this idea may be carried out by the following measuring equipment.

The crystal that is to be measured is placed between two steel plates, the lower of which is joined to a flexible membrane that is mechanically connected to the upper of two capacitor plates as may be seen in Figure 1. Both are loaded by a weight. On this static pressure is superposed an alternating pressure having a frequency of 1 cycle per second obtained by loading and releasing a spring. Thus, charges are generated on the crystal periodically and there are corresponding variations in the capacitance of the capacitor.

In Figure 2, a high-frequency oscillator is tuned primarily by *C1*, across which is the variable capacitor *C2* associated with the crystal. The mechanical coupling between the upper plate of *C2* and the crystal holder is indicated. The 1-cycle-per-second variation in the capacitance of *C2* produces frequency modulation of the high-frequency output of the oscillator.

The frequency-modulated wave is impressed on a circuit tuned slightly off its center frequency so as to produce amplitude modulation through operation on the slope of the resonance curve of the tuned circuit.

A rectifier connected to the tuned circuit will show variations of rectified current that will correspond exactly to the variations of the pressure applied to the crystal and its associated capacitor if the operating point is properly selected. A balancing arrangement suppresses the direct-current component while the alternating-current component generates an alternating voltage across a resistance. This alternating voltage is applied through a variable capacitor *C3* to the piezoelectric crystal in such a manner that by adjusting its phase and amplitude no voltage exists across the crystal. A fast-acting reflecting galvanometer in the anode circuit of an electrometer tube may serve as a voltage indicator.

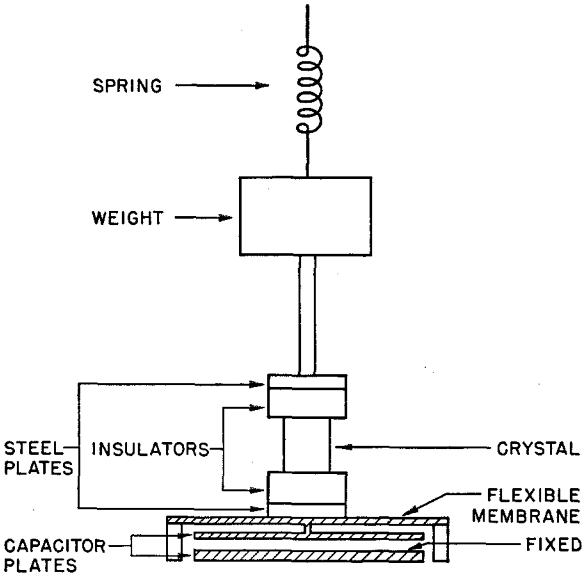

Figure 1—Crystal mounted on a capacitor having a flexible membrane joined to the upper plate. The weight and spring permit periodic variation of the pressure on the crystal and a corresponding variation in the capacitance of the capacitor. A suitable liquid bath maintains at constant temperature the housing in which the crystal and capacitor are mounted.

If a voltage e applied through *C3* is required to balance exactly the alternating voltage generated by the crystal, and if e' is required for *C3*+*C3*, the maximum charge Q produced by a constant alternating pressure on the crystal is

$$Q = \frac{e\, e'\, C_3}{e - e'}. \tag{1}$$

Therefore, we may write

$$\frac{Q}{C_3} = e$$

and

$$\frac{Q}{C_3 + C_3} = e'.$$

If we put

$$e = i\, R$$
$$e' = i\, R',$$

where i is the amplitude of the rectified alternating current and R and R' are the resistances at which e and e', respectively, are generated by i, we may write

$$Q = \frac{i\, R\, R'\, C_3}{R - R'}. \tag{2}$$

In view of the fixed relation between the pressure applied to the crystal and the charge producing it, variations in the alternating current in the discriminator output circuit will be directly related to variations in the pressure on the crystal. The amplitude of the variation in pressure is given by (3).

$$p = \frac{i}{If}, \text{ kilograms}\cdot\text{centimeters}^{-2}, \tag{3}$$

where I represents the variation of current resulting from a variation of 1 kilogram in the mechanical load and f is the area under compression. By combining (2) and (3) and after division by the metalized plated area F, the constant is determined by

$$d_{ik}=\frac{RR'\,C_3\,If}{(R-R')F}, \text{ ampere-seconds}\cdot\text{kilograms.}^{-1} \quad (4)$$

By applying the same variations of pressure to the crystal as well as to the generator of the balancing voltage, the amplitude of the applied oscillating pressure does not appear in the vestigated in both directions. The values show an average error of about 2 percent. Measurements on monoclinic crystals may be regarded as less accurate in view of the very small excitations that had to be measured. Their moduli are therefore less accurate. Since the piezoelectric behavior of monoclinic crystals is very complicated, their smaller moduli are of less importance. Therefore, the investigation of the three monoclinic substances selected was carried out only to determine the largest moduli of the crystals in question.

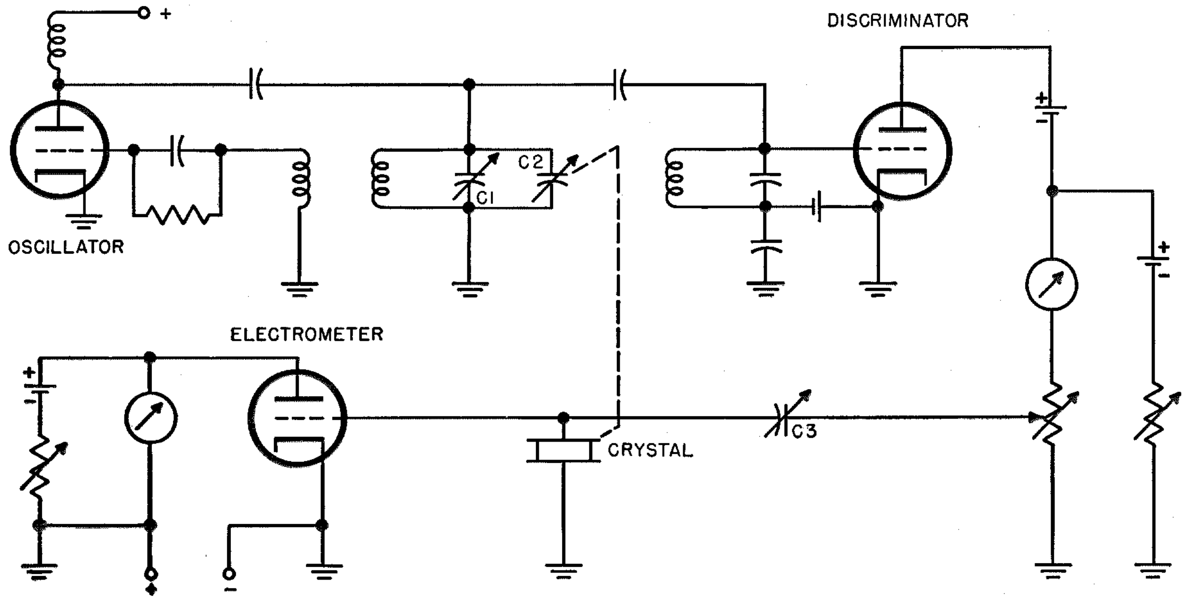

Figure 2—Circuit arrangement for testing crystals.

equation, provided that the voltages generated by the crystal and by the balancing equipment are proportional to the pressure.

For the determination of a modulus, two resistance measurements and one current measurement must be made. From the known variation of *C3* and the dimensions of the crystal to be investigated, (4) may be used to calculate a value that, when multiplied by a factor according to the theory of Voigt, represents the modulus d_{ik}. This modulus is independent of any self-conductivity of the crystal. The observations have been carried out at a temperature of 20 degrees centigrade. The results are average values for several specimens. Where one specimen only was available, the crystal was in-

4. Results of Measurements

All of the modulus values given in this section are in electrostatic units per dyne.[1]

4.1 Quartz

Two circular plates of quartz of equal diameter were cut perpendicular to the electric axis and arranged in such a manner that the longitudinal effects of the piezoelectric voltages created in both crystals were additive.

$$d_{11}=-6.93\cdot 10^{-8}.$$

[1] To convert centimeter-gram-second electrostatic units to meter-kilogram-second (rationalized) units, use the conversion factor $\frac{1}{3}\times 10^{-4}$ coulomb/newton per statcoulomb/dyne.

Furthermore, a crystal already investigated by Voigt was available and was likewise excited longitudinally.

$$d_{11} = -6.94 \cdot 10^{-8}.$$

4.2 Sodium Chlorate

Since Meyer had found a modulus of $NaClO_3$ far higher than that given by Pockels, the modulus d_{14} was measured.

$$d_{14} = -5.23 \cdot 10^{-8}.$$

4.3 Sodium Bromate

Specimen 1: $d_{14} = -7.23 \cdot 10^{-8}$.
Specimen 2: $d_{14} = -7.25 \cdot 10^{-8}$

by transverse observation.

Specimen 3: $d_{14} = -7.33 \cdot 10^{-8}$

by longitudinal observation.

$$d_{14} = -7.27 \cdot 10^{-8}.$$

4.4 Nickel Sulphate Hexahydrate

Specimen 1: $d_{14} = -15.9 \cdot 10^{-8}$.
Specimen 2: $d_{14} = -16.0 \cdot 10^{-8}$.
Specimen 3: $d_{14} = -15.8 \cdot 10^{-8}$
$d_{14} = -15.9 \cdot 10^{-8}$.

4.5 Potassium Phosphate

$d_{14} = -3.85 \cdot 10^{-8}$
$d_{36} = -62.8 \cdot 10^{-8}$.

4.6 Ammonium Phosphate

$d_{14} = +4.35 \cdot 10^{-8}$.
Specimen 1: $d_{36} = -137.5 \cdot 10^{-8}$.
Specimen 2: $d_{36} = -135.9 \cdot 10^{-8}$
$d_{36} = -136.7 \cdot 10^{-8}$.

4.7 Magnesium Sulphate Heptahydrate

Specimen 1: $d_{14} = -6.12 \cdot 10^{-8}$.
Specimen 2: $d_{14} = -6.25 \cdot 10^{-8}$
$d_{14} = -6.18 \cdot 10^{-8}$
$d_{25} = -8.16 \cdot 10^{-8}$.
Specimen 1: $d_{36} = -11.52 \cdot 10^{-8}$.
Specimen 2: $d_{36} = -11.48 \cdot 10^{-8}$.
Specimen 3: $d_{36} = -11.48 \cdot 10^{-8}$
$d_{36} = -11.5 \cdot 10^{-8}$.

4.8 Zinc Sulphate Heptahydrate

Specimen 1: $d_{14} = -5.70 \cdot 10^{-8}$.
Specimen 2: $d_{14} = -5.69 \cdot 10^{-8}$
$d_{14} = -5.70 \cdot 10^{-8}$.
Specimen 1: $d_{25} = -10.5 \cdot 10^{-8}$.
Specimen 2: $d_{25} = -10.4 \cdot 10^{-8}$
$d_{25} = -10.5 \cdot 10^{-8}$
$d_{36} = -9.21 \cdot 10^{-8}$.

4.9 Nickel Sulphate Heptahydrate

$d_{14} = -5.98 \cdot 10^{-8}$.
Specimen 1: $d_{25} = -8.87 \cdot 10^{-8}$.
Specimen 2: $d_{25} = -8.80 \cdot 10^{-8}$.
$d_{25} = -8.84 \cdot 10^{-8}$.
Specimen 1: $d_{36} = -9.65 \cdot 10^{-8}$.
Specimen 2: $d_{36} = -9.60 \cdot 10^{-8}$
$d_{36} = -9.63 \cdot 10^{-8}$.

4.10 Lithium Sulphate Monohydrate

$d_{14} = +11.3 \cdot 10^{-8}$
$d_{15} = -12.0 \cdot 10^{-8}$
$d_{24} = -7.6 \cdot 10^{-8}$
$d_{25} = -2.9 \cdot 10^{-8}$
$d_{31} = -4.0 \cdot 10^{-8}$
$d_{32} =$ very small
$d_{33} = +48.6 \cdot 10^{-8}$
$d_{36} = +19.8 \cdot 10^{-8}$.

4.11 Potassium Tartrate Hemihydrate

$d_{14} = -19.7 \cdot 10^{-8}$
$d_{15} = -12.2 \cdot 10^{-8}$
$d_{24} = -34.6 \cdot 10^{-8}$
$d_{25} = -62.5 \cdot 10^{-8}$
$d_{31} = +2.3 \cdot 10^{-8}$
$d_{32} = +14.4 \cdot 10^{-8}$
$d_{33} = -14.6 \cdot 10^{-8}$
$d_{36} = +18.8 \cdot 10^{-8}$.

4.12 Ammonium Tartrate

$d_{14} = +5.65 \cdot 10^{-8}$
$d_{15} = -14.0 \cdot 10^{-8}$
$d_{24} = -8.5 \cdot 10^{-8}$
$d_{25} = +9.3 \cdot 10^{-8}$
$d_{31} = +1.8 \cdot 10^{-8}$
$d_{32} = +17.6 \cdot 10^{-8}$
$d_{33} = -26.2 \cdot 10^{-8}$
$d_{36} = -5.9 \cdot 10^{-8}$.

Behavior of Gas Discharge Plasma in High-Frequency Electromagnetic Fields*

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THE PURPOSE of this paper is to present the results of an experimental study of some of the properties of the gas discharge plasma. Specifically those properties were studied that are related to the complex conductivity of the gas discharge plasma, when placed in a high-frequency electromagnetic field. Two types of plasma have been investigated; A) the discharge plasma maintained by a direct-current field, and B) the disintegrating plasma obtained after excitation by a pulse of short duration.

It is known that the observable high-frequency phenomena in gas discharges are due to the interaction of the high-frequency fields with the electron gas that is supported by the plasma. To obtain a relatively high density of the electron gas in the plasma, it was desirable to utilize gases capable of supporting free electrons at all velocities. This requirement excluded the use of electronegative gases. As will be apparent, a further selection indicated that the use of gases having high first-excitation levels was preferable for this study. Therefore, the use of monatomic gases and particularly the rare gases was indicated.

The type of discharge used in most of the experiments was cylindrical, with both hot- and cold-cathode structures.

The gas tubes were inserted in a coaxial line to form a portion of the central conductor as shown schematically in Figure 1. Two experiments were performed using a gas-filled rectangular waveguide so arranged that the discharge-tube electrodes did not interfere with the passage of high-frequency waves. In the coaxial-line experiments, the gas discharge tube was arranged so that the diameter of the visible plasma was approximately equal to the diameter of the inner conductor.

For the experiments, a high-frequency electromagnetic wave of the *TEM* mode was transmitted along the coaxial line. When there is no discharge, this wave is greatly attenuated by reflection due to the open section of the center conductor, since this region acts as a waveguide beyond cutoff. If a gas discharge plasma is established in the gap, however, and if the discharge plasma is conductive at the frequency of the electromagnetic wave, the attenuation of the gap is reduced. In addition, the reflected radio-frequency signal is also reduced. The proportions between the reductions in attenuation and reflection may be used to determine the real and imaginary components of conductivity.

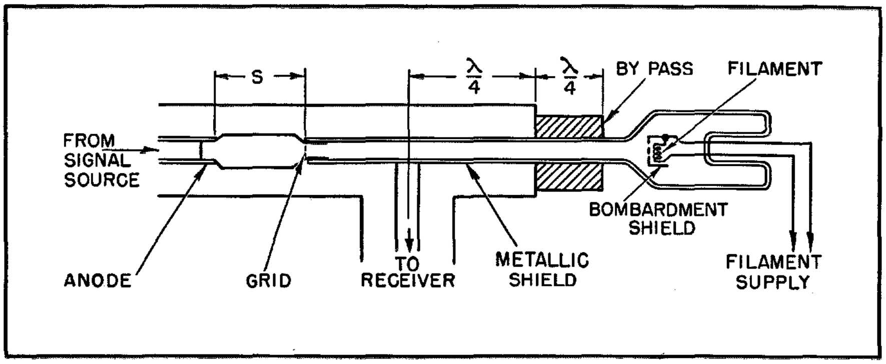

Figure 1—Coaxial gas discharge tube.

In the waveguide experiment with a radio-frequency signal, similar properties of signal reflection, attenuation, and phase-velocity changes should occur. In the case of the waveguide near cutoff, the phase velocity is a very

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† Now with Facsimile and Electronics Corporation, Passaic, New Jersey.

sensitive measure of the dielectric constant. The guide wavelength is given by

$$\lambda_g = \frac{\lambda}{\left[1 - \frac{1}{\epsilon}\left(\frac{\lambda}{\lambda_c}\right)^2\right]^{\frac{1}{2}}} \tag{1}$$

where

λ = free-space wavelength

λ_g = waveguide wavelength

λ_c = cutoff wavelength for air dielectric

ϵ = relative dielectric constant of plasma.

λ_g is plotted as a function of ϵ for $\lambda = \lambda_c/2$ in Figure 2, showing the sensitivity of λ_g-versus-ϵ characteristic for the case where the dielectric constant of the gas discharge plasma is entirely real.

These two types of complimentary experiments provide means to study the discharge plasma under two general conditions. The first, the coaxial-line experiment, aids study in the region of dielectric constants very much less than unity, and the second in the region of dielectric constants close to unity.

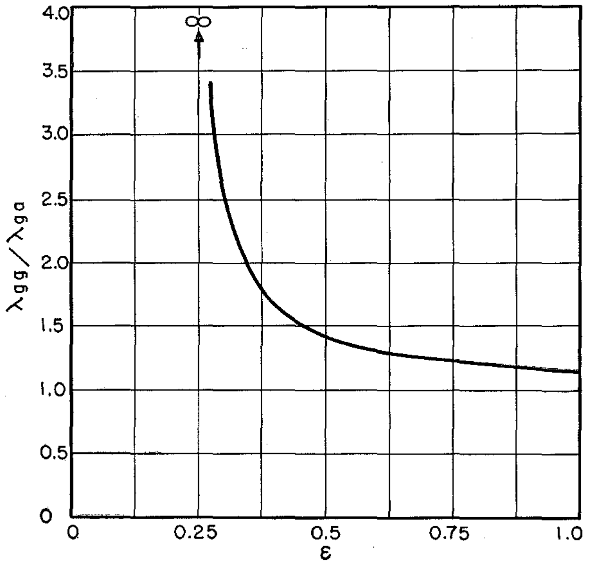

Figure 2—Waveguide wavelength plotted against dielectric constant of the gas discharge plasma $\lambda/\lambda_c = 1/2$.

$$\frac{\lambda_{gg}}{\lambda_{ga}} = \left\{\frac{\epsilon_g[\epsilon_a - (\lambda/\lambda_c)^2]}{\epsilon_a[\epsilon_g - (\lambda/\lambda_c)^2]}\right\}^{\frac{1}{2}}.$$

1. Experimental Setup

The experimental setup for the measurements is shown in Figure 3.

The generator[1] was variable in frequency from 1500 to 2300 megacycles per second and was provided with an attenuator calibrated in decibels with a nominal reference level of 20 milliwatts. Provision is made in the generator for either continuous-wave or pulse-modulated-wave output. In the pulse-modulated-wave case, the pulse was variable from $\frac{1}{2}$ to 30 microseconds.

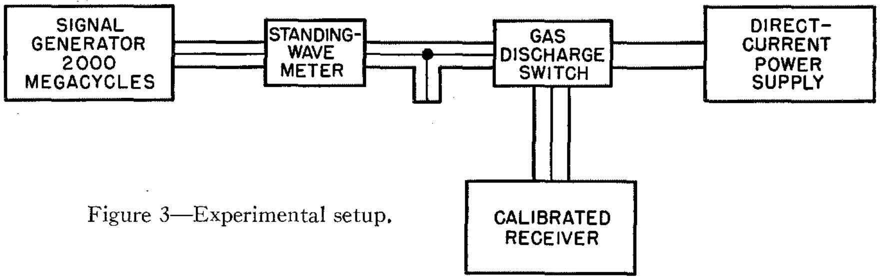

Figure 3—Experimental setup.

The pulse output could be operated synchronously with a trigger generator and could be delayed up to 300 microseconds after the trigger pulse. The transmission line was standard $\frac{7}{8}$-inch (22-millimeter) 50-ohm coaxial line throughout. Two probes were available for the standing-wave meter. The first was a standard crystal-type probe connected to a direct-current galvanometer; the second was a probe that could be attached to the input of a sensitive radio receiver. The radio-frequency receiver was specially constructed for these tests. It consisted of a klystron local oscillator and a low-noise crystal mixer using a type *1N28* silicon crystal feeding a low-noise 30-megacycle intermediate-frequency amplifier.[2] The output of the amplifier was connected to a video-frequency terminal and a thermocouple, the latter being used for power measurements. The receiver, which had a 50-ohm input impedance, had an over-all noise factor of 11.2 decibels[3] and a bandwidth

[1] Type LAG.

[2] A. G. Kandoian and A. M. Levine, "Experimental Ultra-High-Frequency Multiplex Broadcasting System," *Electrical Communication*, v. 26, pp. 292–304; December, 1949: see p. 299.

[3] That is, the noise output referred to the input terminal was 11.2 decibels greater than the theoretical noise 7×10^{-14} watt that would be generated in the input impedance (50 ohms).

of 4.2 megacycles at a center frequency of 2000 megacycles.

Resistive attenuators, each introducing 10 decibels of loss, were used at the output terminal of the generator and the input terminal of the receiver to eliminate possible errors of measurement due to variations in the generator and receiver impedances with changes in signal level.

The power supply consisted of a direct-current variable-voltage supply, which was connected either to the gas discharge tube directly through a current-limiting resistor or to a series-type pulse modulator capable of output currents of several amperes. When pulsed power was used, a variable-pulse-width trigger generator provided for pulses from 0 to 40 microseconds in width at repetition rates from 40 to 1000 cycles.

The output terminal of the receiver was connected to a Dumont type-*248* cathode-ray oscilloscope. This instrument is provided with both a free-running and servo-sweep generator and is suitable for photographing output waveforms. The servo sweep was controlled from the trigger generator for pulsed-discharge studies.

The first experiments were performed using a simple cold-cathode discharge tube. This is shown in Figure 4. The anode end is inserted in one end of the coaxial line as shown. A metallic coating covered the entire length of the tube, except for the gap *S*, and hence comprised a portion of the center conductor. The cathode was located inside the metallic coating some distance from the end of the gap, as shown, and its terminal was brought out of the coaxial line through a quarter-wavelength (at 2000 megacycles) polystyrene choke. A coaxial line to the receiver was attached to the tube a quarter wavelength from the inside end of the choke. Other tubes having similar construction could be readily inserted in place of the one shown in the figure.

The tube was connected through its tubulation to a gas-filling system so that the nature of the gas and gas pressure could be controlled readily.

The gases used in these experiments were helium, neon, argon, krypton, and mixtures of the several gases. Nitrogen, hydrogen, and oxygen were introduced as impurities to study their effects on the rare-gas-plasma properties. The pressures ranged from $\frac{1}{2}$ to 20 millimeters of mercury. The radio-frequency power was limited to about 20 milliwatts or less in all cases.

The attenuation measurements were made with reference to a brass central conductor replacing the gas discharge tube. The radio-frequency attenuation for a given condition of the discharge was measured by raising the input radio-frequency signal level until a standard reading was obtained at the thermocouple output of the receiver. This method maintained the signal-to-noise ratio of the receiver constant and eliminated the possibility that nonlinear gain characteristics of the receiver might distort the measurements.

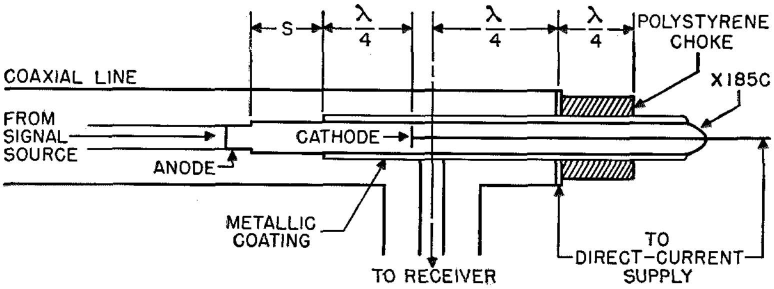

Figure 4—Cold-cathode discharge tube used in first experiments.

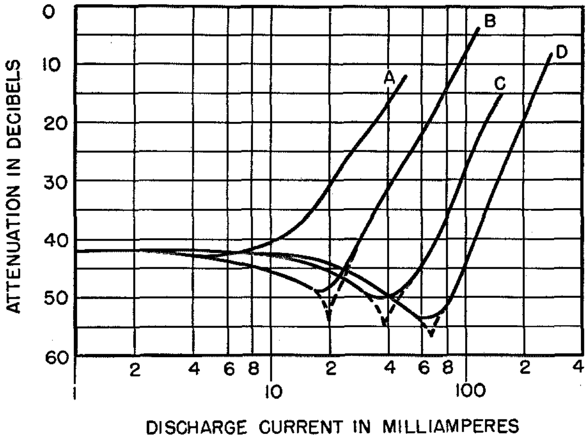

Figure 5—Attenuation as a function of discharge current for: *A*—neon with 1 percent of argon at a pressure of 4.5 millimeters of mercury and *B*, *C*, and *D*—neon at pressures of 4.5, 2, and 1 millimeter of mercury, respectively.

2. *Experimental Results (Coaxial Line)*

Figure 5 shows the attenuation as a function of discharge current for a neon-filled tube at several pressures, and one curve for neon with one percent of argon. Figure 6 shows the results for the same tube filled with several gases at the same pressure (2 millimeters of mercury). The tubes used in these experiments had an inside diameter of approximately 5 millimeters (0.197 inch) in all cases and a total plasma length of over 6 centimeters (2.36 inches). The length of the part of the plasma in the gap was approximately 2.5 centimeters (0.98 inch). It is apparent that the attenuation of the plasma is a function of discharge current for a given pressure. In particular, it is to be noted that as the current is increased, there is a sharp reduction in attenuation from a high value, corresponding approximately to the "cold" attenuation of the gap, to very low attenuation at only slightly larger currents. For example, in the case of the 4.5-millimeter curve for pure neon in Figure 5, for a current increase of from 20 to 100 milliamperes or a ratio of 1:5, the increase in power transmitted through the discharge is 42 decibels or a power ratio of $1.6 \times 10^4:1$. In addition, it is notable that for a certain low-current region, there is an increase in attenuation over that corresponding to the cold or gap attenuation. Considering the first-mentioned effect, the sharp decrease in attenuation with only a moderate increase in current is suggestive of a resonance effect.

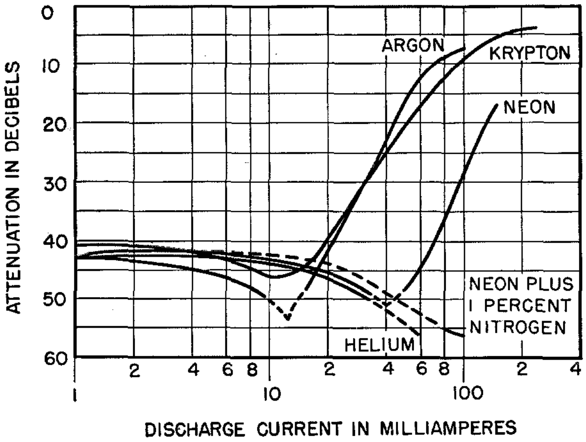

Figure 6—Attenuation as a function of discharge current for several gases at pressures of 2 millimeters of mercury.

It is evident that the plasma has attained a value of electron density that appears to be critically related to the incident signal frequency. It is known that there exists in the high-density plasma a proper frequency of oscillation that is given by the Langmuir–Tonks formula

$$\nu_p = (e^2/\pi m)^{\frac{1}{2}} N^{\frac{1}{2}}, \qquad (2)$$

where

ν_p = proper frequency of plasma oscillation
e = electron charge
m = electron mass
N = electron density.

For the electronic charge, $(e^2/\pi m)^{\frac{1}{2}}$ has a value of 8980. The resonance observed, therefore, would appear to correspond to the value of electron density for which the plasma frequency is of the order of the signal frequency. Under these conditions, if the radio-frequency energy is not sufficiently large to cause an increase in the normal electron-collision frequency, the discharge becomes a good radio-frequency conductor at the boundary that it defines.

If the proper frequency of the plasma electrons is taken into account, the dielectric constant, in the case where the collision frequencies are very small compared to the signal frequency, is given by

$$\epsilon = 1 - \frac{\omega_p^2}{\omega_s^2 - \omega_p^2}, \qquad (3)$$

where

ϵ = relative dielectric constant of plasma
$\omega_p = 2\pi \times$ proper frequency of plasma electrons
$\omega_s = 2\pi \times$ signal frequency.

Since in the cylindrical plasma there is a continuous radial distribution[4] of electron densities having a maximum value at the axis, there is necessarily a continuous spectrum of proper frequencies ω_p limited at the high-frequency side by that corresponding to the maximum electron density. Hence, for all frequencies below this maximum frequency, critical conditions exist in the plasma. Therefore, in the case of a broad-band coaxial system, one would expect substantial radio-frequency energy transmission for

[4] For sufficiently high electron-positive ion densities, the distribution follows the law:

$$N(r) = N_{\max} J_0\left(\frac{2.405\, r}{r_{\max}}\right).$$

all frequencies below a maximum frequency determined by the maximum electron density.

Such a geometry has an essentially wideband transmission characteristic.

An estimate of the electron density based on the random current and electron temperature[5] at a 100-milliampere discharge current yields an electron density corresponding to a plasma frequency ω_p of 2.8×10^9 cycles per second. Hence ω_s is approximately equal to $\omega_p 2^{\frac{1}{2}}$. The difference between the signal frequency and the maximum plasma characteristic frequency is accounted for by the expression for ϵ.

It is to be noted that under certain pressure conditions there is a very sharp *increase* in attenuation at a current just below the rising portion of the transmission curves. Due to the already high attenuation of the gap, and instrument limitations, it was not possible to determine the nature (absorption or reflection) of this increased attenuation. In view of this limitation, no satisfactory explanation was found. It is however believed that this is an absorption phenomenon.

It is seen from Figure 5 that similar attenuation versus current curves are obtained for different pressures, and in particular that the current required for a given attenuation on the rising portion of the curve is higher for lower pressures.

This is due to two principal phenomena. First, one expects that as the pressure is reduced, the average electron velocity is increased for a given current. Accordingly a higher current is required to produce the same electron density and consequent transmission.

The second and probably greater effect is the increase in the diffusion rate of the charges to the walls at lower pressures. Since, as the pressure is reduced the rate of diffusion increases, it is apparent that the drift current necessary to obtain a given electron density is increased. Figure 7, which is a curve of attenuation as a function of pressure for krypton at a constant discharge current, illustrates this effect. The interpretation given is supported by comparisons of the attenuation in different gases at equal or nearly equal pressures. For example, from Figures 5 and 6 at 2 millimeters pressure of argon, an attenuation of 10 decibels is obtained at 70 milliamperes. For neon, the same attenuation requires 185 milliamperes. This is due to the lower diffusion rate of the heavier argon and the lower electron temperatures in that gas. A similar comparison is found between the neon, argon, and krypton gases at other pressures.

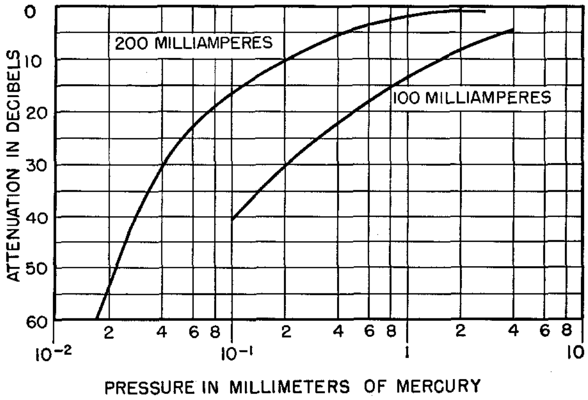

Figure 7—Attenuation plotted against gas pressure for krypton at two constant values of discharge current.

The nature of the gas has a threefold effect. First, for different gases the masses are different. Accordingly the positive-ion mobilities and hence the diffusion rate in the heavier gases are lower. Since, in the current-density region, where the diffusion is ambipolar, the electron diffusion to the walls is controlled by the mass of the positive ions, its rate will be lower in the heavier gases. In addition, the maximum electron velocities are limited by the first excitation level of the gas. Hence the maximum electron velocity will be lower in the heavier gases, which have lower excitation potentials.

So long as the amplitude of the radio-frequency signal is sufficiently small, the effect of the reduction of the first excitation level with increasing mass can be neglected from the point of view of the dissipation in the gas. This leaves then the electron temperature and the diffusion phenomena as the principal controlling factors in the electron density, and hence the imaginary conductivity for the rare gases. The experiments show that in the heavier rare gases at approximately equal pressures the same transmission is attained at lower currents. With regard to the electron removal process, if electron attachment is neglected, one finds, on comparing the possible rate of recombination with the ambipolar

[5] Estimated density $J = Ne\left(\frac{KT_e}{2\pi m}\right)^{\frac{1}{2}}$
$= 2.48\times10^{-14}(T_e)^{\frac{1}{2}}N$, amperes per square centimeter.

diffusion rate, that the electron removal process is controlled primarily by the diffusion, in the pressure range from 1 to 10 millimeters of mercury and for the geometries used. This leads to the conclusion that the principal effect of the nature of the gas in controlling the radio-frequency transmission is the ambipolar diffusion.

3. Transmission in Molecular and Electronegative Gases

A lower electron temperature contributes to a higher value of electron density for a given current. It has been seen from the experiments with gases that a certain minimum electron density is required for good transmission (i.e. the insertion loss must be small compared to the "cold" insertion loss) in a geometry of this type. This concept may be expanded to include other geometries in the sense that the critical value of ϵ in such other geometries represents the region of low radio-frequency-field penetration. Accordingly, it may be deduced that the imaginary conductivity is high under these conditions. It is obvious that for an imaginary conductivity σ_i large compared to the real part of the complex conductivity σ_r, the mean free time T_f of the electrons must be large compared to $1/\omega_s$. For if $\omega_s \sim 1/T_f$, a large fraction of the radio-frequency energy that has been transferred to the electrons is transferred by the electrons to the atoms of the gas and hence lost. If $\omega_s \ll 1/T_f$, relatively little energy can be transferred to the electrons and little or no propagation can take place in the mode considered.

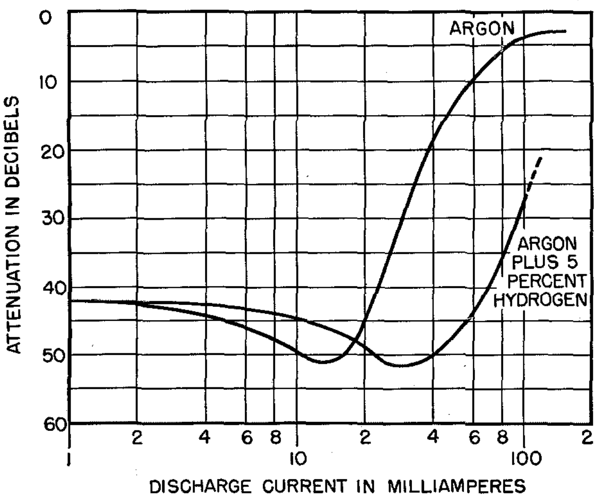

Figure 8—Effect on attenuation of adding 5 percent of hydrogen to argon at a pressure of 1.5 millimeters of mercury.

In the case of a molecular gas of a nonelectronegative nature, such as hydrogen or nitrogen, there are molecular vibrational and rotational excitation levels possible. Therefore, if we consider the probability of cumulative ionization larger than direct ionization, a very large number of electrons is necessary merely to maintain ionization, and hence a large current is required to obtain a given net electron density for the support of a radio-frequency wave.

One would expect, therefore, that to attain a sufficiently high density of electrons having a sufficiently long mean free time to contribute to the propagation of the radio-frequency signal, a very much higher current would be required, as compared with the rare gases. In the case of a mixture of a molecular gas such as hydrogen with a rare gas such as argon, even a small percentage of hydrogen molecules will contribute to the loss of electron density and hence raise the current required. In addition, the principal ionization is in the hydrogen, which has a very much lower mass than argon. Hence, one would expect the ambipolar diffusion rate to be much greater than in pure argon. This tends to decrease further the electron density for a given current density.

The over-all effect is to reduce the radio-frequency transmission; that is to increase σ_r at the expense of σ_i. This is demonstrated in Figure 8, which shows the effect of 5 percent of hydrogen in argon at 1.5 millimeters of mercury. From the curves, for pure argon an attenuation of 30 decibels is obtained at 32 milliamperes, while the same attenuation is obtained in the mixture at 92 milliamperes.

Figure 9 illustrates the effect of the molecular gas without the increased rate of diffusion provided by the hydrogen. In this case, the mixture of 6 percent of nitrogen in helium is compared with helium alone at 4 millimeters pressure, and similar results to the former case are obtained.

In the case of electronegative gases such as oxygen, chlorine, etc., a situation similar to the nonelectronegative molecular gases exists. In these gases, the low-velocity electrons are attached in collision with the gas molecules forming negative ions. Since the mass of negative ions is large, they cannot contribute to the high radio-frequency transmission. Hence the effect of the negative ions formed in the presence of an electronegative gas is to reduce the electron density for a given current. This results in a very much higher current requirement for a given radio-frequency transmission.

The method, described here, of examining the radio-frequency transmission of a gas discharge plasma in a coaxial geometry is suitable to determine concentrations of metastable atoms in the rare-gas discharges. This method compares the electron densities with the radio-frequency transmission characteristic in the gas to be investigated and with the same gas at the same pressure mixed with a small but adequate percentage of a quenching gas. This effect is obtained for example in neon ($V_{met} = 16.6$ electron volts) by mixing a small percentage of argon ($V_{ion} = 15.7$ electron volts) with the neon gas. In this case, a higher radio-frequency transmission occurs and hence higher electron density at lower current. This is shown by comparison of 4.5-millimeter curves for neon and for neon plus 1 percent of argon in Figure 5.

4. *Phase-Shift Measurements of Wave Propagation in a Plasma-Filled Waveguide*

It is well known that the phase velocity of a wave propagated in a dielectric medium is a function of the dielectric constant of that medium. The dielectric here considered is a free electron gas supported by a gas discharge plasma.

Experiments were performed in a rectangular waveguide substantially filled with a gas discharge plasma. The results below are relative to a signal frequency of 9450 megacycles. The gas discharge plasma was contained in a rectangular glass envelope, the walls of which were immediately adjacent to the metallic waveguide surface. The electrodes for the maintenance of the direct-current plasma were arranged so as not to interfere with the transmission of the high-frequency waves through the guide.

The wavelength of a wave propagating in a rectangular waveguide is given by

$$\lambda_g = \frac{\lambda}{[1-(\lambda/\lambda_c)^2]^{\frac{1}{2}}} \tag{4}$$

for an evacuated waveguide ($\epsilon_0 = 1$). In the case of a waveguide filled with a dielectric constituted by a gas discharge plasma, the guide wavelength is given by

$$\lambda_g = \frac{\lambda}{\left[1-\left(\frac{\lambda}{\lambda_c}\right)^2\left(\frac{1}{1-\frac{4\pi Ne^2}{m\omega^2}}\right)\right]^{\frac{1}{2}}} \tag{5}$$

(when the imaginary part of the dielectric coefficient is negligible compared to its real part).

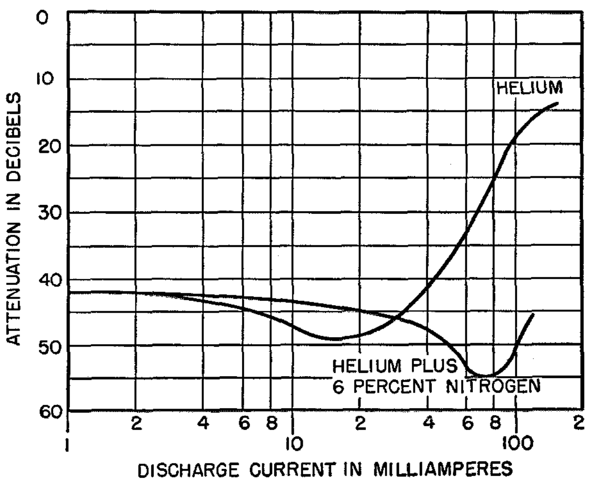

Figure 9—Effect on attenuation of adding 6 percent of nitrogen to helium at 4 millimeters pressure.

N is the electron density, assumed here to be uniform over the cross section of the guide.

The variation in λ_g due to the dielectric constant of the plasma results in a phase shift of

$$\phi = \frac{2\pi}{\lambda}\left\{\left[1-\left(\frac{\lambda}{\lambda_c}\right)\right]^{\frac{1}{2}} - \left[1-\left(\frac{\lambda}{\lambda_c}\right)^2\left(\frac{1}{1-\frac{4\pi Ne^2}{m\omega^2}}\right)\right]^{\frac{1}{2}}\right\} \tag{6}$$

radians per unit length. It is then expected that one could produce a variation in λ_g by varying the electron density N. This of course is readily accomplished by controlling the discharge current.

The experiments were performed using a waveguide section 45 centimeters long. A bridge arrangement, shown in Figure 10, was used for the determination of the phase shift. With no discharge present, the position of the standing-wave minimum was determined and the shift in position measured as a function of discharge current.

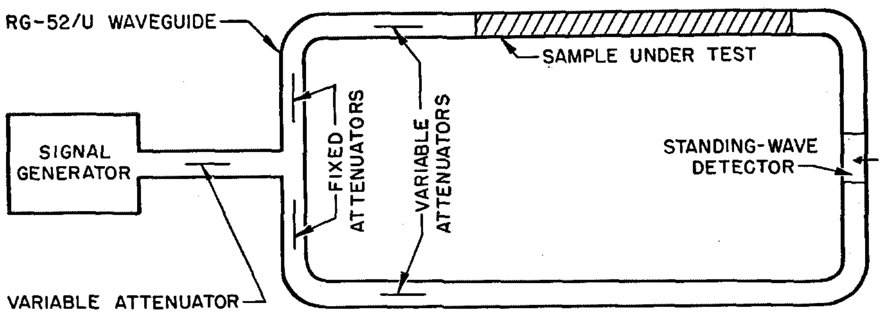

Figure 10—Test setup for measuring phase shift through a gas-discharge-plasma-loaded waveguide.

Figure 11 shows the phase shift as a function of discharge current. It will be noted that, under the particular conditions indicated, the phase shift is a substantially linear function of current. This type of measurement leads to a convenient method for determining average electron densities.

5. *Presence of Noise in Gas Discharge Plasma*

It has become evident that the electrons in the gas discharge plasma are capable of supporting radio-frequency signals incident upon it. That is, the plasma is a medium in which wave propagation obtains due to the interaction fields among its constituents. One would expect, therefore, that under favorable conditions (i.e. negligible absorption) and in favorable geometries, any local disturbance within the plasma would be propagated through it and produce an observable effect in an external circuit. One would expect this effect to be of the nature of random noise.

To study the existence and nature of this noise, an experimental setup was arranged as follows.

The same type of microwave setup used in the transmission measurements was used for noise measurements. It is shown in Figure 12. The load was a 50-ohm coaxial load that matched the transmission line. The other microwave terminal pair was connected to the receiver through a short coaxial cable.

The receiver was the same used for the conductivity tests. A galvanometer, connected to the thermocouple, was used to indicate the radio-frequency power into the receiver.

The most convenient power standard available (for a large number of successive measurements) was the receiver noise itself. Accordingly, all noise measurements were made with reference to the receiver noise. Periodic checking of the receiver noise factor against a standard-signal generator insured the accuracy of this reference.

The noise measurements were made in a limited bandwidth, and it is to be remembered that the values obtained are power averages over the band. In view of the high frequency used (2000 megacycles), this does not represent a serious limitation on the quality of the measurements.

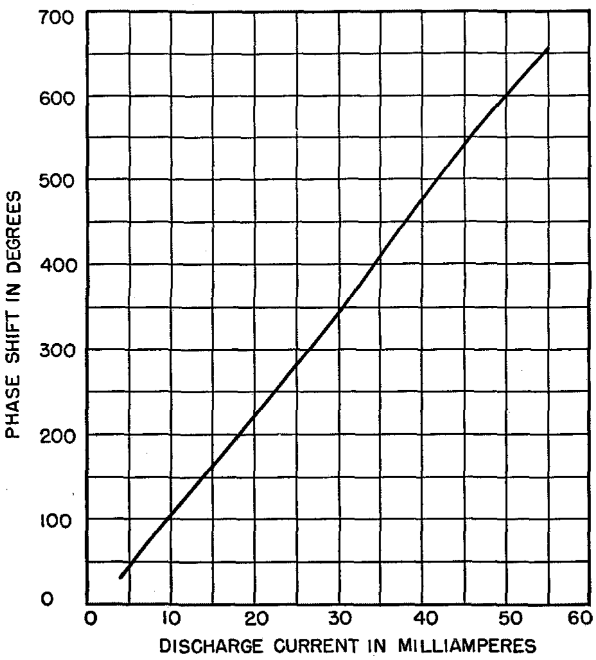

Figure 11—Phase shift plotted against discharge current for 18 inches (46 centimeters) of *RG-52/U* waveguide within which was a rectangular glass tube 1.9 by 0.8 centimeters (0.75 by 0.315 inch) filled with neon and argon at a pressure of 1.5 millimeters of mercury. The excitation frequency was 9450 megacycles.

6. *Noise Experiments and Experimental Results*

A considerable number of noise measurements as a function of the nature of the gas, gas pressure, and the discharge current were made for a direct-current discharge. In general, the results were similar to those presented here, and these are typical. The particular measurements made were for continuous direct-current discharge conditions in a hot-cathode tube. The cathode was shielded by a tantalum cylinder, which is entirely outside the radio-frequency circuit. A sketch of the tube is shown in Figure 1.

The noise observations were made in the absence of any radio-frequency signal.[6] Typical experimental curves available are shown in Figures 13, 14, and 15. It is seen that they all have similar characteristics, rising to a broad smooth peak in the 60-to-150-milliampere range and then decreasing, for all gases and pressures used. Equipment limitations prevented measurements for currents greater than about 250 milliamperes in most cases. Figure 16 shows the attenuation and the corresponding noise

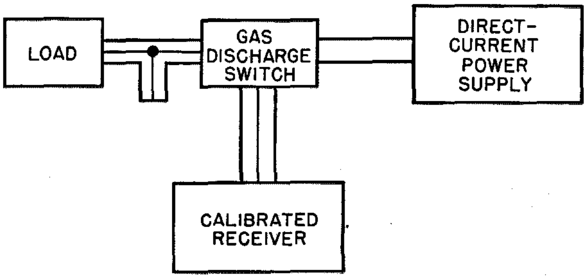

Figure 12—Equipment arrangement for noise measurement.

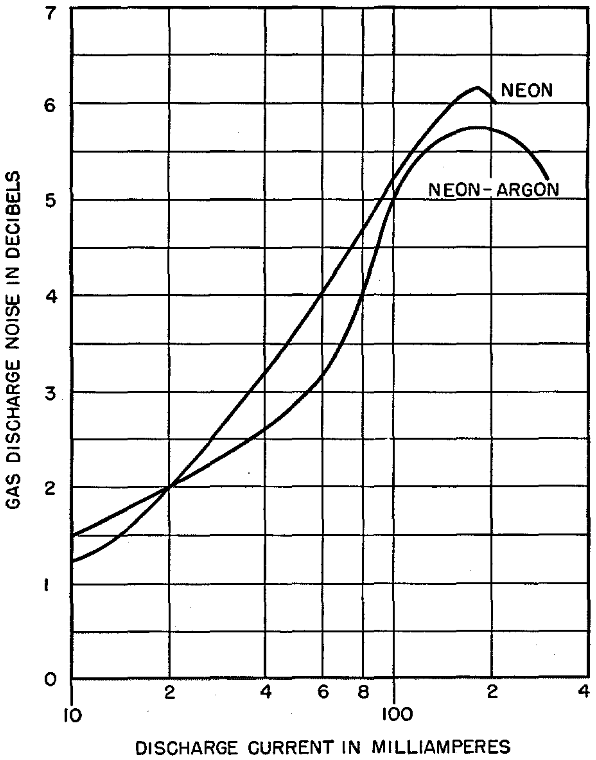

Figure 13—Plotted against discharge current in milliamperes is the gas discharge noise in decibels referred to a level corresponding to the receiver output noise, which was 11.2 decibels above the theoretical noise of 7×10^{-14} watt for a bandwidth of 4.2 megacycles at 2000 megacycles. The curves are for neon at 1 millimeter pressure and for neon plus 1 percent of argon at 2 millimeters pressure.

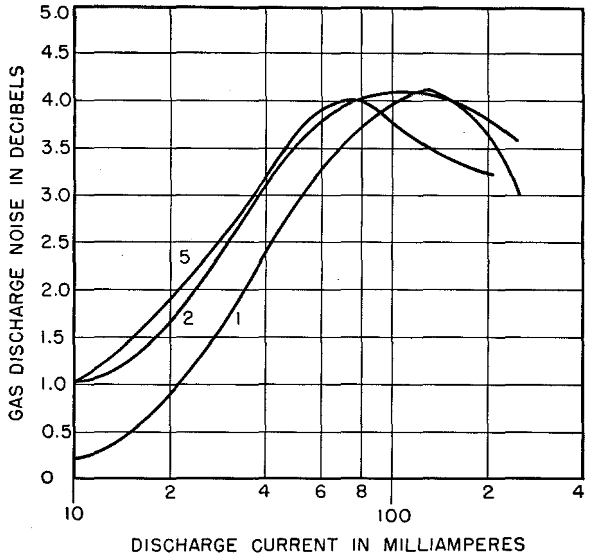

Figure 14—Curves similar to those of Figure 13 but for krypton at the indicated pressure in millimeters of mercury.

[6] In the presence of an externally applied radio-frequency signal of considerable amplitude, it was observed experimentally that an oscillation in the region from 5 to 20 kilocycles per second appeared. The amplitude of this oscillation increased with increasing signal amplitude. This oscillation can be accounted for only by the discharge tube itself, and evidently appears in the output of the 2000-megacycle receiver due to a modulation by the discharge plasma of the radio-frequency signal by a low-frequency oscillation generated within the plasma. This oscillation frequency is too low to be accounted for by either an ionic collisional noise or a plasma oscillation. It is probable that the low-frequency signal is due to a hydrodynamic type of oscillation. Since this low-frequency oscillation is apparently capable of modulating an externally applied signal, it is probable that it also modulates the high-frequency noise produced in the discharge, increasing the total noise energy radiated by the discharge.

characteristic as a function of current for krypton at a pressure of 2.3 millimeters. It is apparent that the peak of the noise characteristic occurs in the current region of the knee at the top of the transmission characteristic.

In view of the limited experimental information available in 1946–1947, when this work was conducted, it was difficult to draw any definite conclusions as to the cause and nature of the noise generated in the discharge plasma, but it now seems likely that the noise at high frequencies is due to collisional noise, electronic density fluctuations in the plasma, or more probably both.[7–9]

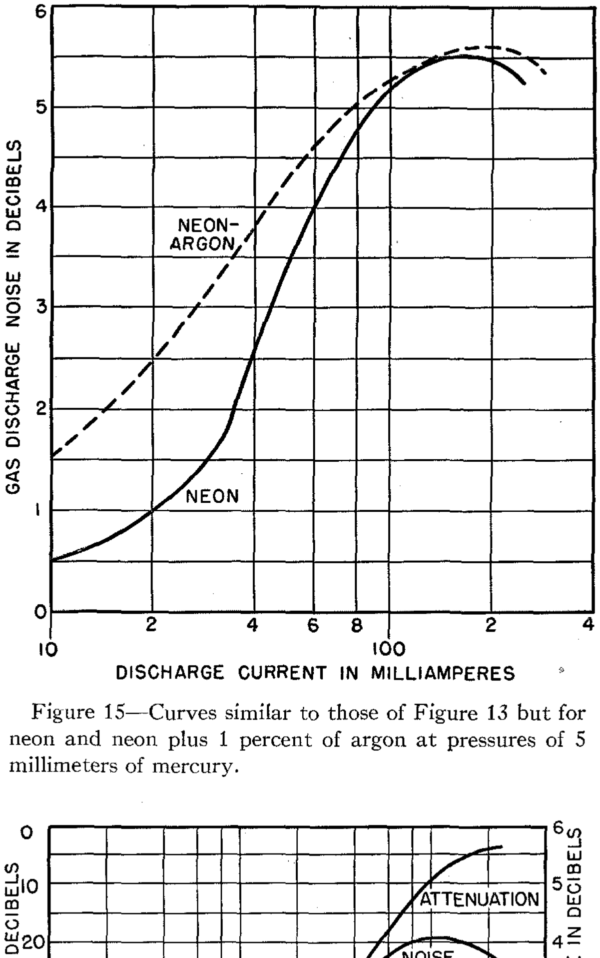

Figure 15—Curves similar to those of Figure 13 but for neon and neon plus 1 percent of argon at pressures of 5 millimeters of mercury.

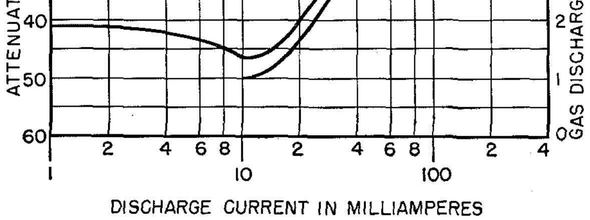

Figure 16—Attenuation and noise plotted against discharge current for krypton at a pressure of 2.3 millimeters.

7. *Experimental Study of Radio-Frequency Transmission Under Transient Conditions*

Since experimental facilities (as well as power dissipation within the discharge) limited the use of direct-current in excess of 250 to 300 milliamperes, it was found desirable to apply pulse techniques to obtain higher discharge currents and hence higher electron densities. Thus, while in the direct-current discharge, transmission never reached 0 decibel, it appeared possible to determine whether an increase in transmission occurred at higher electron densities not otherwise attainable. By the application of a short pulse of the order of a few microseconds of high amplitude, the entire transmission characteristic, for a wide range of electron densities in the disintegrating plasma, is readily observable. By the same token, disintegration times of the decaying plasma, and the law of disintegration can be obtained.

By using a radio-frequency signal essentially as a probe to study the discharge plasma the limitations imposed by the permanent nature of the usual physical probe are avoided. The radio-frequency signal probe may be applied or removed at will and, furthermore, its time of application and removal relative to the initiation of the discharge may be controlled over limits determined only by the complexity of the auxiliary apparatus used. Because the radio-frequency field will be used as probe, its amplitude must be sufficiently small so that the energy contributed by it does not materially affect the normal electron energy distribution within the discharge. Specifically, the amplitude of the radio-frequency field must be such that

[7] L. Goldstein and N. L. Cohen, "Radiofrequency Conductivity of Gas-Discharge Plasma in the Microwave Region," *Physical Review*, v. 73, p. 83; January 1, 1948.

[8] W. W. Mumford, "Broad-Band Microwave Noise Source," *Bell System Technical Journal*, v. 28, pp. 608–618; October, 1949.

[9] P. Parzen and L. Goldstein, "Current Fluctuations in the Direct-Current Gas Discharge Plasma," *Physical Review*, v. 82, pp. 724–726; June 1, 1951.

the amplitude of electronic oscillations imposed by the field are very much smaller than the normal electronic mean free path.

By varying the frequency of the radio-frequency signal, phenomena that differ with gas pressures may readily be examined.

It is to be noted that this method of studying the discharge is limited to those processes that involve the electron density and electron distribution functions of the discharge. In addition, the sensitivity of the method depends principally on the noise generated by the receiver.

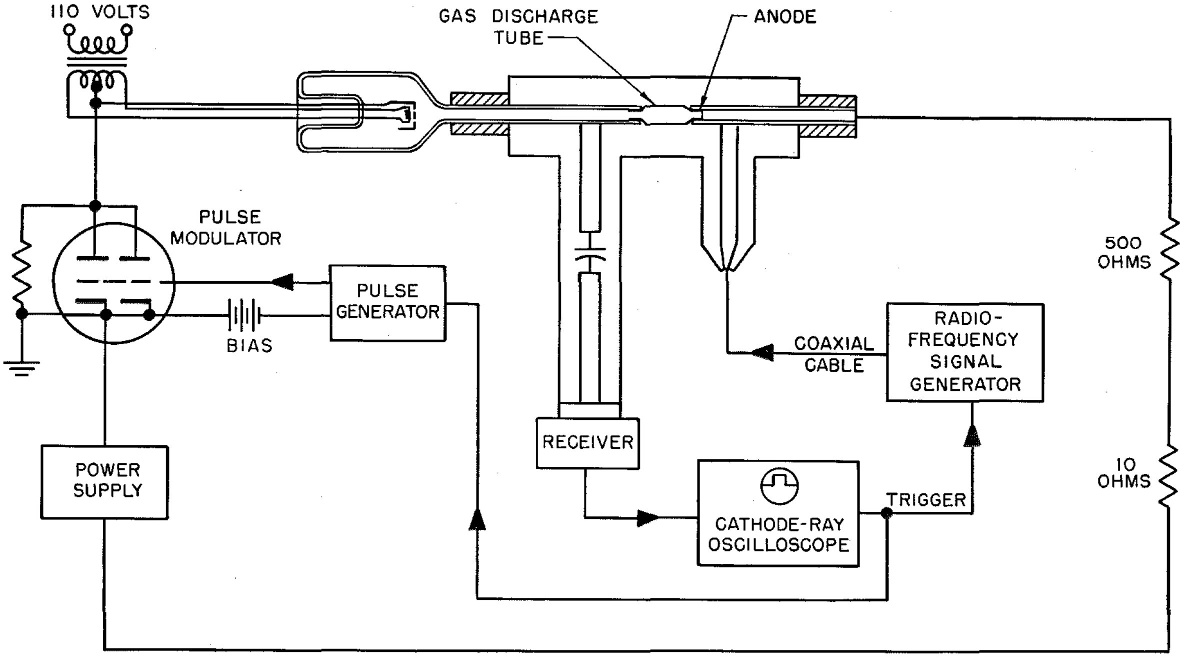

Figure 17—Pulse-transmission setup.

The decay or disintegration of the plasma after removal of the exciting field is a fruitful region for study by this method.[10] The disintegration time observable by means of the radio-frequency signal, of course, depends on the nature of the gas, gas pressure, and intensity of the discharge. The times of decay of transmission (and, hence, electron densities) observable by this method at the frequency used exceeded several microseconds, in even the most mobile gases at pressures of the order of 1 to 10 millimeters of mercury. In addition, it is possible to examine in some detail production of electrons by secondary sources during the disintegration time. The time limitation in this case is the disintegration of the electron density to a level that results in a radio-frequency signal attenuation down to the receiver noise level.

[10] Since this work was started, a similar method has been described by S. C. Brown *et al.*, Massachusetts Institute of Technology, Research Laboratory of Electronics Report; May, 1948.

The method is obviously only sensitive to variations in electron density that cause a change in the radio-frequency signal output at least as great and preferably greater than the amplitude of the receiver noise.

The types of measurements that are possible with the radio-frequency equipment are essentially of two kinds. The first of these is the power transfer measurement, and the second is the power reflection measurement. These may be likened to measurement of the iterative and transfer impedances of a two-terminal pair.

In the most practical terms, the first measurement is an attenuation measurement of the amount of radio-frequency signal that appears at the output of the gas discharge for a given input. The second measurement is the voltage-standing-wave-ratio measurement common to distributed-parameter experimental work.

8. Experimental Setup and Method of Measurement for Transient Transmission

The experimental setup for the transient transmission measurements is shown in Figure 17.

The gas discharge tube was placed in the coaxial line as in the case for the direct-current measurements. The anode was connected through a current-limiting resistor to the direct-current power supply. The cathode of the discharge tube was connected through a "series" pulse modulator to ground. The pulse modulator was shunted by a relatively high resistance that allows a small current to be maintained in the discharge tube, as desired. The pulse modulator consisted of two type *3E29* tubes in parallel operating in the normally cut-off condition. The grids of the modulator tubes were supplied by a pulse from a pulse generator. The amplitude of the pulse was adjustable, as was the duration. The pulse duration was from ½ to 100 microseconds. For pulse durations up to 10 microseconds, the rise time was approximately ¼ microsecond with a flat top and a decay of about ¼ microsecond. For pulse durations exceeding 10 microseconds, the pulse had a rise time of about 1 microsecond.

The radio-frequency signal generator was connected to one of the radio-frequency terminals. The same receiver used in the direct-current discharge transmission and noise measurements was connected to the other output terminal of the coaxial line, through a 20-decibel radio-frequency attenuator section. The output of the receiver was connected to a Dumont type-*248* cathode-ray oscilloscope. This oscilloscope is provided with a servo sweep of adjustable duration and time markers for calibrating the sweep. It also contains a trigger-signal generator, which was used to trigger the pulse generator and servo sweep simultaneously. The radio-frequency signal generator could be operated either with a continuous-wave signal output or with a pulsed radio-frequency signal output. The radio-frequency pulse was adjustable over a range of ½ to 30 microseconds, and could be delayed from the trigger time up to 300 microseconds. The trigger source in the cathode-ray oscilloscope was used to trigger the radio-frequency pulse, when required.

With this arrangement, it was possible to examine the radio-frequency transmission as a function of time in two ways.

The first method was to scan the transmission pulse arising out of the applied discharge pulse with a narrow radio-frequency pulse. With this method, the radio-frequency pulse was set at any desired time up to 300 microseconds after the discharge-current pulse, and the attenuator on the signal generator was set for a standard amplitude of the detected radio-frequency pulse on the cathode-ray tube. The reference level used was the transmission with the discharge tube off. This method allowed detailed examination of the transmission phenomena, and in principle appeared useful. It was found, however, that in certain cases for various reasons the radio-frequency transmission of the decaying plasma changed slowly with time. Since this method of study required considerable time for accurate measurements, a second semi-quantitative method was also used.

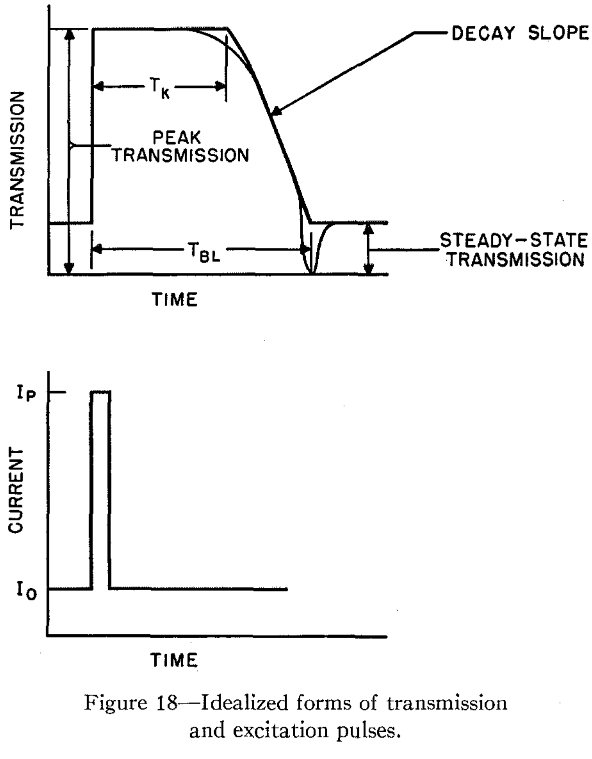

Figure 18—Idealized forms of transmission and excitation pulses.

This involved applying a continuous-wave radio-frequency signal to the discharge tube and photographing the cathode-ray tube while the discharge was being pulsed. This necessitated

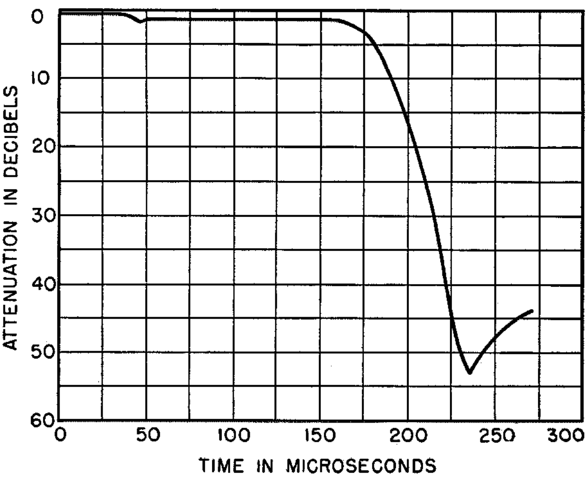

Figure 19—Attenuation values immediately following the removal of a discharge pulse in argon at a pressure of 1.5 millimeters of mercury. The pulse went from a steady-state current of 25 milliamperes to a peak value of 1.5 amperes for 10 microseconds. The ranges of uncertainties for the curve are 20 microseconds and 2 decibels.

operating the discharge for only a few seconds at a time. The results obtained were of limited utility, since the measurements had to be made from a photograph of the transmission pulse. In addition, it was desirable to place considerable attenuation between the radio-frequency output of the coaxial line and the receiver input. This limited the dynamic range observable to about 20 decibels above the receiver noise level in most cases. It did allow an accurate determination of the flat portion of the transmission and the upper part of the decay characteristic, in keeping with the repeatability of the experiments, and in this respect was very useful. The general transmission pulse shape is shown in Figure 18.

9. Experiments and Results

The first experiments were performed using the pulse-scanning method. The results indicated that, in general, the attenuation characteristic of a disintegrating plasma in a rare gas are described essentially by a curve with a flat portion of relatively low attenuation for some time after the removal of the driving pulse, a rapidly increasing attenuation to a value greater than the steady-state condition, followed by a return to the normal steady-state value.

A typical attenuation characteristic is shown in Figure 19. This particular measurement was made under the conditions indicated. It is to be noted that, in this case, the attenuation of the gap is only slightly larger than 0 decibel for about 40 microseconds after the removal of the energizing pulse. Thence there is a drop to a slightly larger attenuation until about 170 microseconds, when a rapid change sets in. It is to be noted that the maximum attenuation exceeds the "ultimate attenuation" determined by the value of the keep-alive current. This particular curve is more or less typical of the type of attenuation characteristic found with rare gases. The small variation in the transmission at around 40 microseconds appears to be due to a phenomenon that acts to alter suddenly the electron density or energy-distribution function, and is of the order of magnitude of the minimum variation to which the radio-frequency method is sensitive.

It is now of interest to examine in some detail the observed properties of the disintegrating plasma.

The cases discussed below were all studied in a hot-cathode gas discharge tube. Several different tubes were used, but all had essentially the same structure in the region of the gap. This construction is shown in Figure 1.

The several experiments performed were made in hydrogen, the rare gases, and mixtures of the

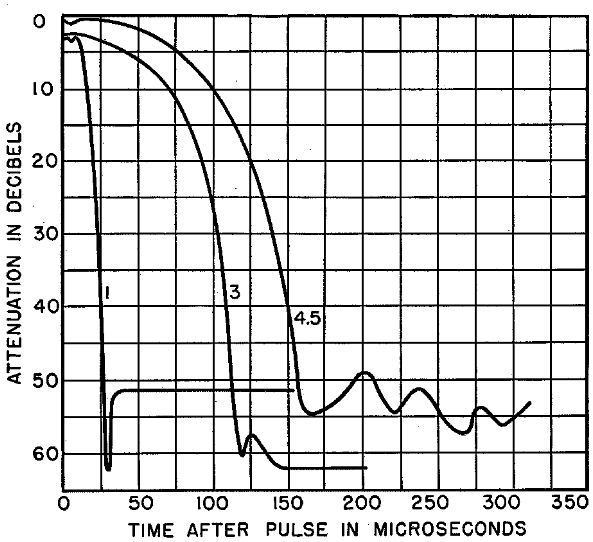

Figure 20—Attenuation plotted against time after the discharge pulse for helium at the indicated pressures in millimeters of mercury. The discharge pulse went from a steady-state current of 30 milliamperes to a peak value of 0.5 amperes.

rare gases at pressures up to about 10 millimeters of mercury. The controllable variables in the experiments were the duration of the exciting pulse, pulse amplitude, pressure, and nature of the gas.

Figure 20 shows the attenuation of the disintegrating plasma as a function of time for

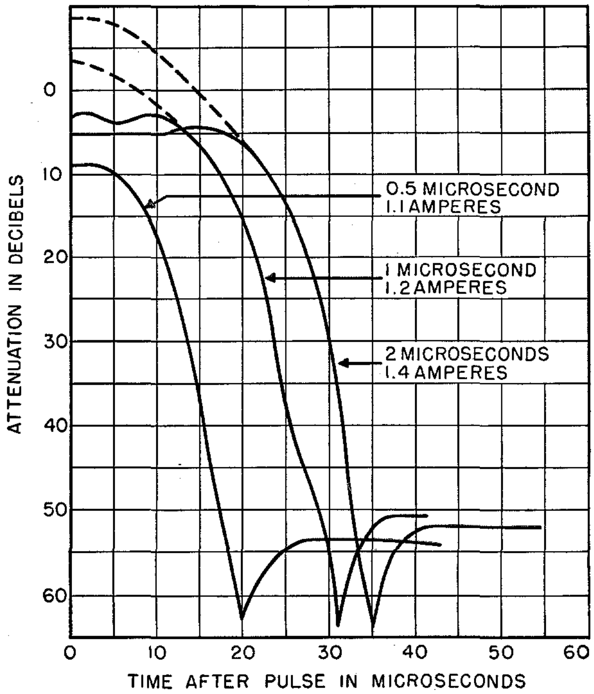

Figure 21—Attenuation after discharge pulses for helium at 1 millimeter pressure for pulses of the duration and current amplitudes indicated on the curves. The steady-state current was 30 milliamperes in each case.

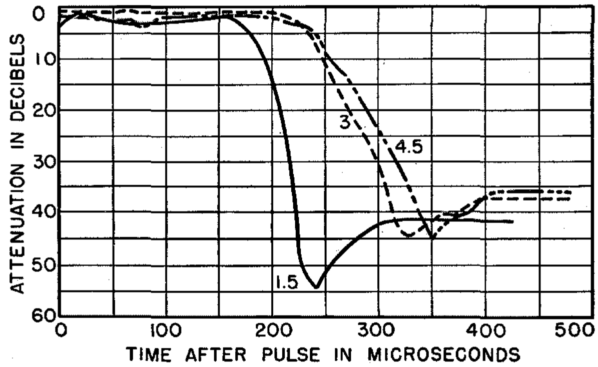

Figure 22—Attenuation plotted against time after a 1-microsecond discharge pulse in argon at the pressures indicated in millimeters of mercury. The pulse current was 1 ampere and the steady-state current was 25 milliamperes.

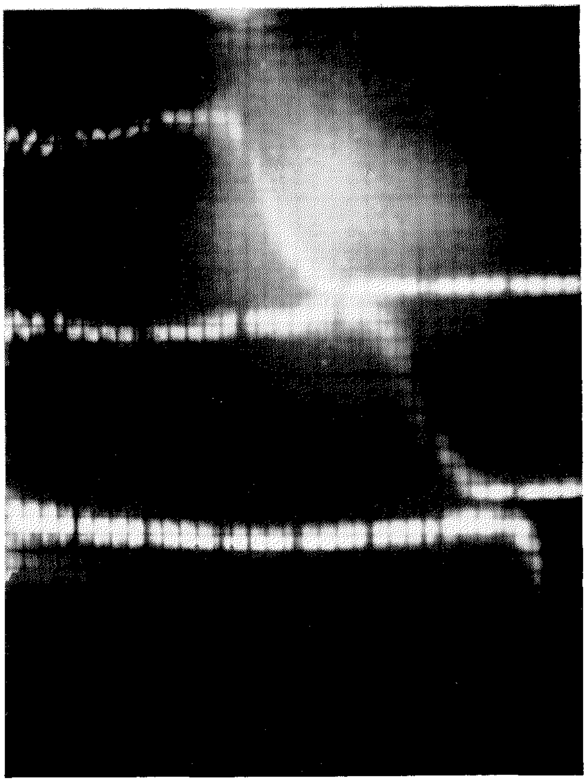

Figure 23—Oscillograms of transmission properties of neon with 1 percent of argon at pressures of 1 (uppermost curve), 2, and 3 millimeters of mercury. Steady-state current was 25 milliamperes with 1.5-ampere 1-microsecond pulses. The markers are at 10-microsecond intervals.

helium at 1, 3, and 4.5 millimeters pressure, other conditions being the same. It is seen that the duration of the transmission pulse increases with pressure. Figure 21 shows attenuation for helium at 1 millimeter pressure for exciting pulses of 0.5, 1, and 2 microseconds in duration. Here, it is seen that the duration of the transmission pulse is a function of the duration of the exciting pulse. Figure 22 shows the characteristics for argon at three different pressures. Here, again, the transmission time increases with pressure. Figures 23, 24, and 25 show transmission of the disintegrating plasma for various experimental conditions. It will again be noted that the general shape of the transmission pulse is similar to the pulse shown in Figure 18. T_{BL} (Figure 18) is taken as an arbitrary reference corresponding to the point where the received radio-frequency signal is of the same order as the receiver noise (i.e. 20 decibels below the maximum received-signal value). From some of these data, Figures 26 and 27 have been prepared. From Figure 26, it appears that the duration of the transmission increases approximately linearly with the amplitude of the exciting pulse, as would be expected. Other conditions being constant, the total number of electrons produced is proportional to the current, and if those phenomena that act to remove the electrons are essentially linear, it would be expected that the total transmission decay time would increase with increasing initial supply, up to the point where the electron-removal processes operate at rates comparable with the production process. From this set of curves, it also is apparent that the total decay time increases with the larger gas mass, with the exception of neon–argon mixture. This case is somewhat different and will be discussed later.

Figure 27 is a plot of transmission decay slope (i.e. from the end of the "flat portion" to the base line), as a function of exciting pulse current, other conditions being constant. Here it is evident that the rate of decay is lower in the heavier gases, again with the exception of the neon–argon mixture. All of these curves show a sharp peak in slope below about 0.8 ampere. Disregarding this for the moment, it would appear that both the total decay time and the decay time beyond the flat portion of the transmission characteristic increases with increasing mass. Now the principal causes of disintegration of the electron density in the plasma are due to three possible phenomena. They are diffusion, recombination, and attachment.

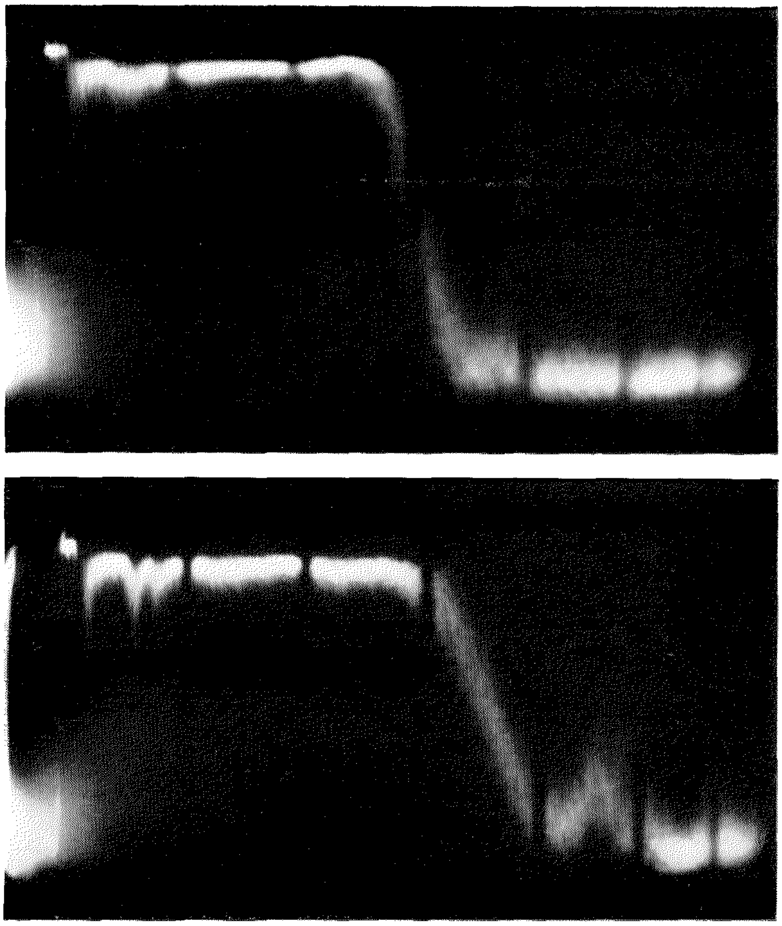

Figure 24—These two oscillograms are for neon at 1 millimeter of pressure following 1-microsecond 1.5-ampere pulses. Upper curve is for a steady-state current of 25 milliamperes while the lower curve is for zero steady-state current. The markers are at 10-microsecond intervals.

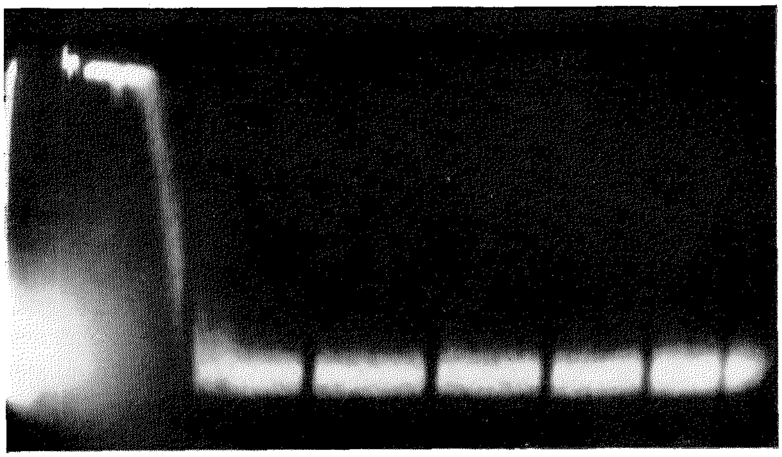

Figure 25—Behavior of argon at 1 millimeter pressure following 1-microsecond 1.5-ampere pulse from zero steady-state current. Markers are at 10-microsecond intervals.

The gases used, according to the manufacturer, contained no measurable amount of electronegative gases. The possibility of oxygen, the principal electronegative impurity likely to be present, was determined essentially by the exhausting and gas-filling system. Hence, if any electronegative impurity existed, it probably existed in about the same proportion in all gases. It may be noted that the usual precautions were made to minimize the possibility of impurities being present in the gas. This leaves then the possibility of recombination and diffusion. Since the recombination coefficients in the rare gases are of the same order of magnitude and in general quite small (although for thermal electrons fairly large),[11] it would appear that

[11] M. A. Biondi and S. C. Brown, "Measurements of Ambipolar Diffusion in Helium," *Physical Review*, v. 75, pp. 1700–1705; June 1, 1949.

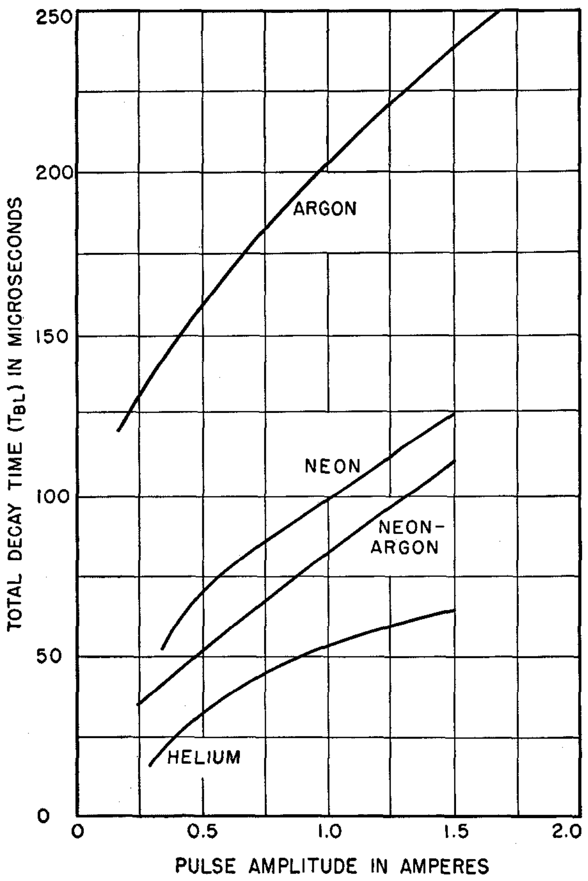

Figure 26—Total transmission decay time T_{BL} plotted against the amplitude of a 1-microsecond pulse, starting from a 20-milliampere steady-state condition, for several gases at pressures of 2 millimeters of mercury. Neon–argon indicates 1 percent of argon in neon.

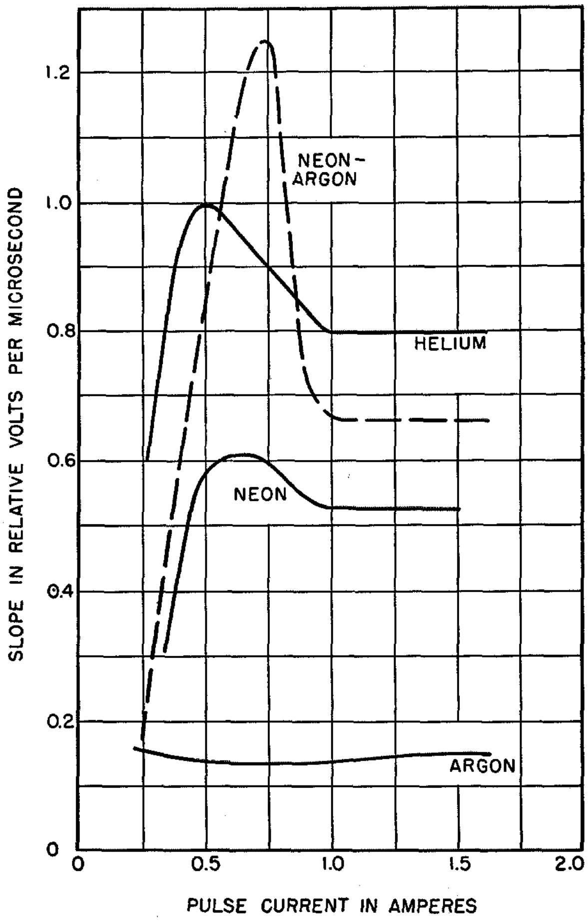

Figure 27—Rate of transmission decay as a function of the amplitude of 1-microsecond pulses starting from 20 milliampere steady-state conditions. The gases indicated (neon–argon being 1-percent argon) are at pressures of 2 millimeters of mercury.

at these pressures and in this geometry the principal cause of electron removal is the diffusion phenomenon.

Comparing the curves of neon with neon plus 1 percent argon in Figure 27, it appears that in the presence of a quenching gas, the mass of the gas is not the principal factor in determining the duration of the disintegrating plasma. It is noted that the rate of decay of the neon–argon mixture is considerably greater than that of pure neon, which evidently has approximately the same mass. It would appear that the retransfer of accumulated potential energy of the excited atoms into kinetic energy of secondary electrons is an important factor in the duration of the disintegrating plasma. The rapid quenching action of the argon atoms on the neon metastable states removes them as a source of potential energy for the production of secondary electrons in the disintegrating plasma, thereby shortening the life of the plasma.

Furthermore, in the disintegrating plasma, since in the mixture the ions are mainly argon ions, the ambipolar diffusion rate is greater than the diffusion rate of neon ions in neon, or argon ions in argon. This is due to the improbability of charge exchange between the argon ions and neutral neon atoms. This would seem to be confirmed by the position of the neon–argon curve in Figure 27.

In the pressure range investigated (1 to 10 millimeters of mercury), and for electron densities high enough that the main removal process is diffusion (in these cases ambipolar), one expects a longer disintegration time with increasing pressure. An example of the experimental data in this connection is shown in Figure 20.

10. Conclusion

It is well known that an electron gas can define boundaries for the propagation of an electro-magnetic wave. Ionospheric studies have determined that relatively low free-electron densities (approximately 10^5) provide conductive boundaries at low radio frequencies but a refractive medium to wave propagation at higher radio frequencies.

An experimental study of this phenomenon has been made in the microwave region in a wave-guide system, the necessary high electron densities associated with these frequencies being obtained by the use of space-charge compensation. This necessary space-charge compensation is most readily obtained by use of the positive ions existing in the gas discharge plasma.

The experiments show that the high electron densities required for propagation in this region with no appreciable losses are readily obtained with the use of limited exciting power.

In the course of this work, it became apparent that the techniques developed are applicable to the study of many of the detail phenomena occurring in gas discharges.

Correction for

Suppression of Harmonics in Radio Transmitters

By GEORGE T. ROYDEN

In this paper, which appeared on pages 112 through 120 of Volume 28, Number 2, dated June, 1951, equation (4) on page 117 should be

$$C = \frac{A}{(r + rR^2/F^2)^{\frac{1}{2}}}.$$

Magneto-Optics of an Electron Gas for Guided Microwaves: Propagation in Rectangular Waveguide*

BY LADISLAS GOLDSTEIN, M. A. LAMPERT, AND J. F. HENEY

Federal Telecommunication Laboratories, Incorporated; Nutley, New Jersey

We have previously described[1] magneto-optical effects in microwave propagation experiments in circular waveguide. The magneto-electronic medium in the guide was an electron gas immersed in a uniform direct-current magnetic field parallel to the axis of the guide. The main experimental results consisted of polarization transformations of a TE_{11} wave initially launched in the guide with linear polarization. The results were interpreted satisfactorily in terms of the different propagation characteristics in the anisotropic medium of the two oppositely rotating, circularly polarized TE_{11} modes that the empty circular guide supports.

The purpose of this note is to describe the results of propagation experiments with the same magneto-electronic medium in a rectangular waveguide. Both the results and their interpretation are quite different from those briefly mentioned above. In this case, the empty guide at the frequency employed supports only one propagating mode, namely the TE_{10} mode so that no polarization transformations can take place. The relevant propagation measurements in the empty guide outside of the medium are those of the amplitudes and phases of the transmitted and reflected waves. The main results of these measurements are —A) very large attenuations of the signal in the region of magnetic-field intensities where the gyrofrequency of the electrons approximates the signal frequency; B) large reflections at magnetic-field intensities immediately on either side of gyroresonance; and C) small or negligible reflection at gyroresonance. Thus, the very large attenuation at gyroresonance appears to be the result of absorption in the medium in accordance with theoretical prediction. In the accompanying figure, these results are illustrated for a particular experiment under conditions there indicated.

Further results are—A) increasing the gas pressure tends to widen the resonance and decrease its magnitude; B) at sufficiently low pressure (below about 0.1 millimeter of mercury in our experiments) the width of resonance appears to be determined by other factors than pressure, such as nonuniformity of magnetic field in the medium; and C) the phase of the reflected wave varies very sharply in the gyroresonance region. That these results are essentially independent of the gas is evidenced by the fact that similar phenomena were observed also in krypton, xenon, hydrogen, and mercury vapor.

The resonance curves have precisely the shape to be expected from the typical anomalous dispersion of the dielectric constant in the region of a proper frequency of the medium, here the electron gyrofrequency. The anomalous dispersion of the magneto-electronic medium has been previously established[2] at lower frequencies. However, in our experiments the length of the anisotropic medium exceeded two free-space wavelengths; so that true propagation phenomena have been observed.

We believe that the observed phenomena are general, to the extent that they are characteristic of electromagnetic wave propagation in the magneto-electronic medium (with longitudinal magnetic field) in any guiding system that supports only a single mode of propagation at the frequency employed.

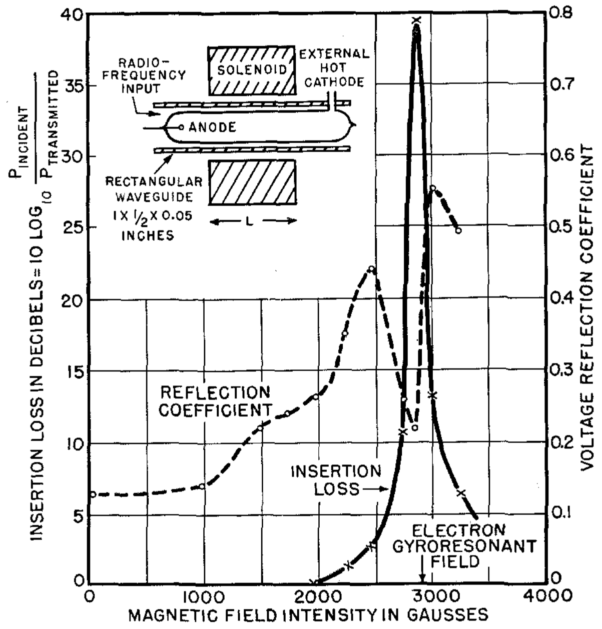

Figure 1—Transmission and reflection characteristics *versus* magnetic field intensity. Signal frequency = 8200 megacycles per second. Gas is neon plus 1 percent argon at 0.1 millimeter of mercury pressure. The discharge conditions are: a steady direct-current plasma at 465 volts and 30 milliamperes (current-limiting resistor of 10,000 ohms included). Length L of solenoid is 5 inches (approximately 2 guide wavelengths).

* Reprinted from *Physical Review*, v. 82, p. 1255; September 15, 1951. This work was sponsored by the Signal Corps.

[1] L. Goldstein, M. A. Lampert, and J. F. Heney, "Magneto-Optics of an Electron Gas with Guided Microwaves," *Physical Review*, v. 82, pp. 956–957; June 15, 1951: also *Electrical Communication*, v. 28, pp. 233–234; September, 1951.

[2] S. Benner, *Naturwissenschaften*, v. 17, p. 129; 1929: H. Gutton, *Annales de Physique*, v. 13, p. 62; 1930: L. Tonks, *Physical Review*, v. 37, p. 1458; 1931: E. Appleton and F. Chapman, *Proceedings of the Physical Society*, Part 3, v. 44, pp. 246–254; May 1, 1932.

Contributors to This Issue

NATHANIEL L. COHEN

NATHANIEL L. COHEN was born on December 12, 1922, at New York City. He received the B.S. degree in electrical engineering from the College of the City of New York in 1943 and the M.S. degree from Polytechnic Institute of Brooklyn in 1949. He served as an instructor in the latter school during 1942.

From 1943 to 1948, he was with Federal Telecommunication Laboratories, where he worked on radar components and systems and on gas discharge tubes. On leave of absence, he served on a special task force for the Secretary of War during 1944 and 1945.

In 1948, he became chief engineer of Facsimile and Electronics Corporation.

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J. L. GOODWIN

LADISLAS GOLDSTEIN. A photograph and biography of Dr. Goldstein appears on pages 237–238 of the September, 1951, issue.

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J. L. GOODWIN was born at Chigwell, England, in 1920. He studied electrical engineering at the Borough Polytechnic and Twickenham Technical College, receiving the higher national certificate in 1947.

During the war, he did research work on underwater acoustics with the Admiralty and in 1948 he joined the staff of the transmission division of Standard Telephones and Cables.

Mr. Goodwin is a Graduate Member of the Institution of Electrical Engineers.

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JOHN F. HENEY. A photograph and biography of Mr. Heney appears on page 238 of the September, 1951, issue.

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G. KING received the B.Sc.Eng. degree from the City and Guilds of London College in 1938. During the following year he served that institution as a demonstrator.

From 1939 to 1945, he was at the Admiralty Signal Establishment at Witley. He then returned to his alma mater as a lecturer in communications for a year.

Mr. King joined Standard Telecommunication Laboratories in 1946 as head of the microwave department and is now head of the materials division. (Mr. King's paper appeared in the preceding number of this volume.)

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MURRAY A. LAMPERT. A photograph and biography of Mr. Lampert appears on page 238 of the September, 1951, issue.

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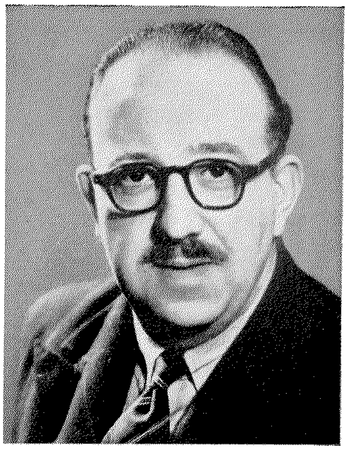
ERNEST G. ROWE was born in 1909 at Plymouth, England. He received from London University an honours degree in engineering in 1932 and a M.Sc. degree a year later.



ERNEST G. ROWE

He joined the development staff of the M. O. Valve Company in 1933, becoming later chief of valve development.

At the end of 1948, he was named chief receiving-valve engineer of the Brimar Valve Division of Standard Telephones and Cables, Limited.

Mr. Rowe is a Member of the Institution of Electrical Engineers, an Associate of the City and Guilds of London Institute, and holds the diploma of the Imperial College of Science and Technology.

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FRIEDRICH P. SPITZER was born at Magdeburg, Germany, on June 24, 1914. He was educated in physics and applied electricity at the universities of

FRIEDRICH P. SPITZER

Berlin and Göttingen. After obtaining his academical degree from the University of Göttingen in 1938, he continued there doing crystal research at the Physics Institute.

From 1939 until 1945, he worked on radar developments for the German navy and then joined the staff of the Institute of Physical Chemistry at Göttingen for research on the ferroelectricity of crystals.

Since 1949, he has been engaged in the development of piezoelectric crystals at the Nuremburg laboratory of Standard Elektrizitäts–Gesellschaft A.G.

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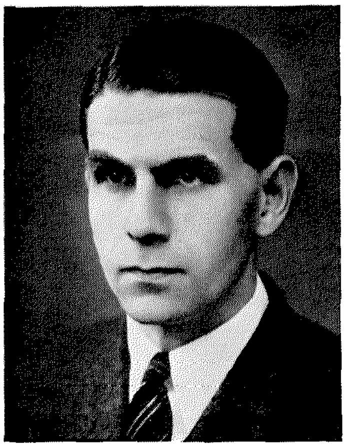

G. M. B. Wills

G. M B. Wills was born at Marlow, England, in 1915. He received the B.Sc. (Eng) degree and the A.C.G.I. from the City and Guilds (Engineering) College of the University of London.

From 1937 to 1939, he served as a development engineer for Standard Telephones and Cables, Limited. During the following seven years, he was an officer, attaining the rank of Major, in the Royal Corps of Signals. From 1942 to 1945, he was attached to the Indian Posts and Telegraphs Department and worked in that country on a telecommunication development plan.

After six months during 1946 with Standard Telephones and Cables, Limited, he joined the Brazilian Telephone Company. Recently, he was transferred from the transmission to the equipment department.

Mr. Wills is an Associate Member of the Institution of Electrical Engineers.

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Compañía de Teléfonos de Chile, Santiago, Chile

Compañia Telefónica de Magallanes S.A., Punta Arenas, Chile

Cuban American Telephone and Telegraph Company, Havana, Cuba

Cuban Telephone Company, Havana, Cuba

Compañía Peruana de Teléfonos Limitada, Lima, Peru

Porto Rico Telephone Company, San Juan, Puerto Rico

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Compañía Internacional de Radio Boliviana, La Paz, Bolivia

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Mackay Radio and Telegraph Company, New York, New York[2]

All America Cables and Radio, Inc., New York, New York[3]

Sociedad Anónima Radio Argentina, Buenos Aires, Argentina[4]

[1] Cable service. [2] International and marine radiotelegraph services.
[3] Cable and radiotelegraph services. [4] Radiotelegraph service.

Laboratories

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