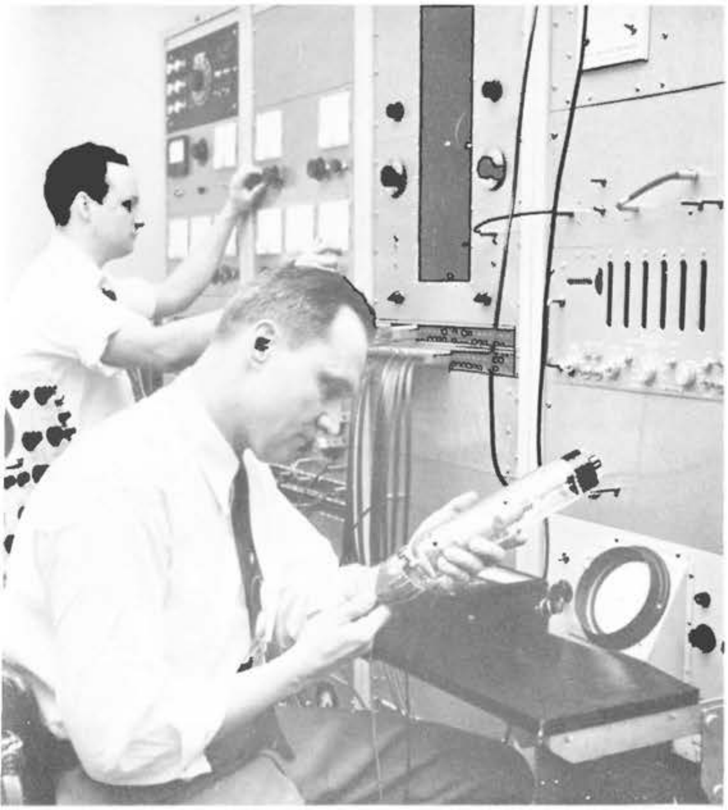

Mechanized Memory and Logic— What Electronics Can Do

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The terminology of electronic switching—with its "barrier-grid memory tubes" and "transistorized logic circuits" — may seem strange to people who are familiar only with present-day telephone equipment. Despite its seeming complexity, however, electronic switching promises a wholesale simplification of telephony. Laboratories engineers believe that in the future it will be a faster and more economical way to provide telephone service.

In many magazines and newspapers you may see claims about the "magic" of electronics. As telephone people, we are not interested in magic, but we are interested in the capabilities of electronics, because electronics will penetrate into areas of the telephone business that either have never been mechanized before or have been mechanized by other means. Perhaps we can sharpen our appreciation of the part electronics can play by first examining the characteristics that cause people to associate words like "magic" with it.

Looking for fundamentals, we may inquire, "What puts the magic into modern electronics?" The answer comes in two parts: (1) the ability to develop tremendous but stable amplification, and (2) the ability to perform complex operations in millionths of a second. The first of these is familiar to telephone people, for it is the basis of our modern telephone transmission plant. Electronic amplifiers are the muscles of our transmission system. The second is being applied extensively in new switching systems now under development.

The automatic tracking radars developed at Bell Laboratories and manufactured by Western Electric are a splendid example of these two abilities of electronics. The Nike guided missile system, Figure 1, naturally excites a writer to the use of words like "magic" and "giant brain" when he attempts to describe its performance. Without the magic of almost unlimited amplification, the radar would never be able to hear the radio echo which bounces off an airplane many miles away and spreads out into space, because only an extremely small fraction of the energy returns to the radar antenna. This small echo is amplified billions and billions of times and is strengthened to where it can drive motors which cause the radar antenna to follow the enemy plane as it goes across the sky.

At the proper instant a missile is launched by the Nike system, and here the system shows its brain power. By exploiting the ability of electronics to perform complex operations in microseconds, an electronic computer guides the missile toward the target. Even if the target should attempt to evade the missile, the very high speed computer takes account of the evasion, and the missile proceeds inexorably to the interception.

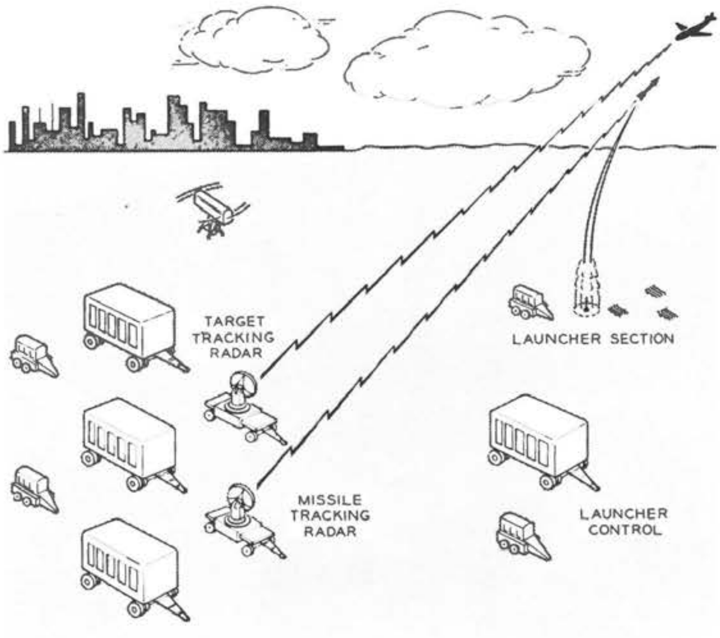

Fig. 1 — The Nike missile system.

Since the telephone plant is not a radar system and since telephone customers do not need to be connected together in microseconds, how shall the second magic-giving characteristic of electronics be exploited in the telephone plant? The answer is, "Through time sharing". Now, time sharing is just another way of describing the common-control operations that we introduced into the telephone plant with the dial system many years ago. With common control, one expensive piece of equipment performs in sequence the same function for a number of different customers. We are limited in time-sharing electromechanical devices because of their limited speed. When we go to electronics, however, we can design complex equipment which completes a function in a few millionths of a second and is then ready to do something else. To appreciate the full power of such electronic speeds, consider a machine that can complete an operation every millionth of a second. Assume also that a man may take a minute to perform the same operation. At these speeds the machine could perform as many operations in a minute as a man could by working night and day for an entire lifetime. Such speed results in great economic advantages for electronics.

We can develop some insight into the fundamentals of time sharing by analyzing the case of the chessmaster, who sometimes plays and wins as many as 30 games of chess simultaneously. Now he doesn't really make the individual moves of these games simultaneously. He moves quickly from board to board and takes on each opponent in turn. He has memorized the positions of the pieces and the previous history of each game, and all he has to do is detect the new move made by an opponent. He rapidly decides upon his next move, executes the move, and then goes to the next board. Note what this chessmaster has been doing. First of all, the whole secret of his success is his ability to remember a tremendous amount of information. In fact, he carries around with him a memory of all the games. The other ingredient in his success is the ability to make decisions very rapidly. As a result, his 30 opponents are, in effect, engaged continuously. We can do this kind of time sharing in telephony with modern electronics.

Imagine now a central office which has a built-in "chessmaster". This electronic wizard plays a game with each telephone customer who wants service. His goal is to meet the service needs of each customer. The "boards" the "telephone-master" uses are the lines of 10,000 or so telephones that come into the office. The "telephone-master" continuously scans these lines to determine if service is requested. He remembers what progress he has made in carrying out the wishes of each of the customers, and he makes decisions on what his next move with each customer should be. He does all these things so rapidly that every telephone user thinks he has the undivided attention of the central office equipment.

The chessmaster used both memory and logic, and it is primarily because memory and logic have been mechanized in modern electronic computers that people compare these machines to the human brain. Since mechanized memory and logic will be at the center of future telephone switching systems, it is important to understand their fundamentals and applications.

We may call to mind one example of mechanized memory from the folklore of the wild West. Every time a gun-fighter killed a man he cut a notch on the stock of his gun. Any time he wanted to refresh his memory he could go to the "mechanized memory" on the gun stock and run his finger down it. This may seem like a rather trivial example, but it illustrates some of the fundamental principles of mechanized memory systems. A modern counterpart of the notched gun stock is the punched card used in modern accounting machines. This card has holes punched in it, and the positions of these holes represent information. A punched card can, for example, remember a man's social security number or it can remember his rate of pay.

To understand the ideas behind electronic memory it is well to keep in mind the idea of a notch, or a hole, or some other physical modification as the basis for mechanized memory. Other key ideas will be explained with reference to Table I in which are listed some of the words and phrases used in describing electronic memory systems.

A very basic word is BIT – a contraction of BINARY DIGIT. A BIT is the elementary unit of information. It is the yes or no answer to a question. The power of such answers is indicated by the familiar game of 20 questions. As you know, by asking no more than 20 questions it is generally possible to find out which object out of all the objects in the world a person has in mind. The following example shows how yes-no answers can be used to represent numbers. Suppose someone has a number between zero and 31 in mind and we ask this person in succession the following questions and get the answers indicated.

"Is the number greater than 15?" "Yes." "Is the number greater than 23?" "Yes." "Is the number greater than 27?" "No." "Is the number greater than 25?" "No." "Is the number greater than 24?" "Yes." Now from this pattern of answers – Yes, Yes, No, No, Yes – we know that the decimal number is 25. We can write the number twenty-five in binary notation by saying that "yes" corresponds to the digit *one* and a "no" corresponds to the digit *zero*. Thus the binary number twenty-five is written 11001. By asking five questions we have determined the magnitude of a number between zero and thirty-one. By asking ten questions we could have identified any number between zero and a thousand. By asking 20 questions we could have identified any number between zero and a million. Thus any number between zero and a million could be written as a 20-digit binary number.

TABLE I – WORDS TO REMEMBER

Binary Digit	Bit
Access	Address
Read	Write
Destructive Reading	Regeneration
Volatile	Barrier-Grid Memory Tube
Magnetic-Core Memory	

Why bother with binary representation of numbers? The reason is that a binary digit is something like a notch on a gun or a hole in a paper card. It is very definite. There is either a hole in a card or there isn't. Similarly a binary digit is either a *one* or it isn't. Binary digits can be conveniently represented by a variety of components. For example, a relay is either operated or not operated. We can say that the operate condition represents a *one* and the unoperated condition represents a *zero*. Similarly, a transistor can be allowed to represent a *one* when it conducts or a *zero* when it is not conducting. A capacitor can represent a *one* when it contains stored electrical energy, whereas an uncharged capacitor can be used to represent a *zero*. A magnet can be magnetized in such a way that the north pole is at the top or it can be magnetized so that the north pole is at the bottom. Thus the number twenty-five might be represented as a row of magnets that are magnetized North-North-South-South-North.

In addition to the problem of providing the individual memory cells, the designer of a mechanized memory system must provide many other features indicated by some of the words in Table I. These functions will be explained with reference to Figure 2, which shows a pigeonhole memory system. Assume each pigeonhole has a card in it, Figure 2 (a), and that information is stored or remembered on each card. Going to the memory and selecting a particular card is the ACCESS operation. The READ operation is simply the operation of looking at the card. Clearly, the ACCESS operation must precede the READ operation. Similarly, to WRITE into the memory involves an ACCESS operation, because we

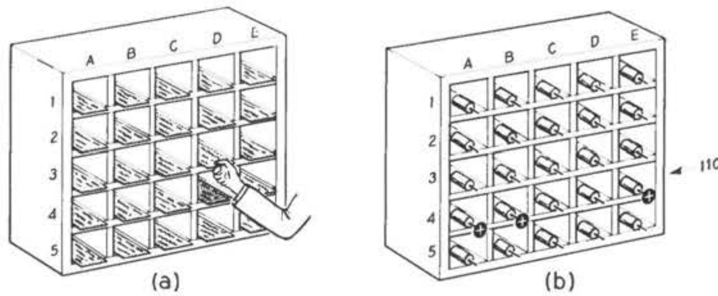

Fig. 2 — A "pigeonhole" memory system: (a) with cards in holes and access to address D3; (b) with capacitors in holes and binary digits 11001 registered in Row 4.

must first find the card we are interested in. To gain access to information systematically, it is customary to provide addresses which give instructions on how to get to each pigeonhole. ADDRESS D3, for example, says go out to the D column and then proceed down to the third row to information cell D3. With the aid of such a pigeonhole memory system, we have developed the fundamental ideas of mechanized memory – the idea of ADDRESS, the problem of ACCESS, the concept of BINARY DIGITS and BIT OF INFORMATION, the WRITE operation and, finally, the READ operation.

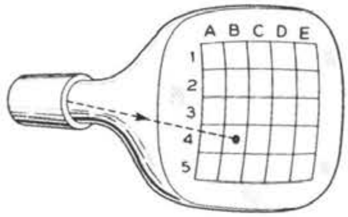

Fig. 3 — Pigeonhole system on face of a television tube.

An electronic system, however, could not be based on a man running around writing on cards, so a more suitable record is needed to put in the pigeonholes. Earlier, when developing the idea of bits of information, it was pointed out that a capacitor could be used to store information. To develop a memory system, we can obtain lots of capacitors and put one in each pigeonhole, Figure 2(b). Suppose you want to write the binary number 11001 into the memory. First of all, at what address will the information be written? Assume that it is to be written in Row 4. Proceed down to Row 4. The first digit is a *one*, so charge the first CAPACITOR. Since the second digit is also a *one*, charge the second CAPACITOR. Since the third and fourth digits are zeros, leave the third and fourth CAPACITORS uncharged. The fifth digit is *one*, so charge the fifth CAPACITOR. Other numbers might be stored in other rows. To read the number at Address 4 at a later time we would short circuit the CAPACITORS in Row 4; whenever we got a spark we would know that a one had been stored.

This leads to another basic idea. After the information has been read, where has the information gone? It has been destroyed because short circuiting capacitors was a DESTRUCTIVE READING process. Memory designers must design REGENERATION into memory systems in which reading is destructive. If you want to read information from the capacitor-memory and still leave the information ready to be read again at a later time, you must put energy back into the capacitor if it was storing a *one*. This combination of a read and write operation is known as REGENERATION. If a capacitor memory sits idle for several days, eventually the charge leaks off the capacitor and the memory is said to be VOLATILE. In such VOLATILE memories the designer insures against amnesia by requiring the memory system to read periodically its contents and also to regenerate them.

An electronic system with capacitors in the pigeonholes is not complete because someone has to walk around charging and discharging the capacitors. To see how the access problem can be solved with electronics, consider the ordinary television set. As you know, the picture is drawn by a spot of light that chases back and forth across the face of the picture tube. This spot of light is a kind of electronic pencil that is time-shared to draw the TV picture. Imagine the face of the picture tube divided into pigeonholes as in Figure 3. The spot of light on the picture tube can be deflected by voltages to any desired address in a millionth of a second. This rapid deflection of an electron beam provides almost instantaneous access to any one of a group of pigeonholes.

How can information be stored on the screen of a cathode ray tube? Physicists have developed a new kind of tube called a BARRIER-GRID MEMORY TUBE. This tube is like a TV picture tube except that it has literally thousands of tiny capacitors deposited on the screen. The electron beam in this tube can charge or discharge capacitors. Thus, in the memory tube, Figure 4, we have a means of gaining access not to just 25 but to over 16,000

Fig. 4 — W. W. Baldwin welding leads to contacts on glass envelope of barrier-grid memory tube.

pigeonholes. The memory tube then has a memory capacity of 16,000 bits. To get an equivalent memory capacity with relays would require 16,000 relays. A memory tube is a splendid example of the compactness that can be achieved through electronics. It has, in addition, the tremendous advantage that reading and writing into the tube requires only a few millionths of a second.

A while back we discussed the possibility of a

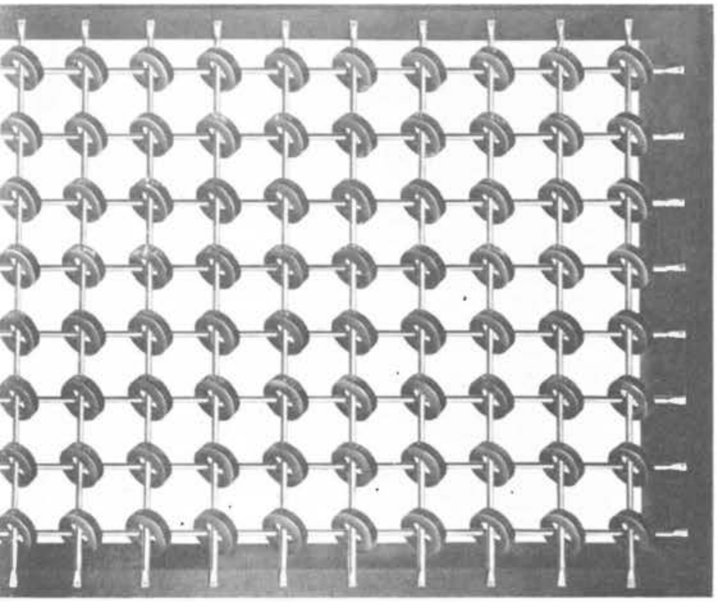

Fig. 5 — Magnetic-core memory: direction of magnetism of selected cores is reversed by currents in wires.

magnetic memory. This is another important method of storing large amounts of information in a small space. It would be cumbersome if conventional magnets were used, but physicists have discovered ways of making up a ceramic-like magnetic material (ferrite) into little doughnuts called "cores". In a magnetic-core memory, Figure 5, electrical conductors run through the holes of numbers of these doughnuts mounted in an array. Currents passing through certain of the wires will magnetize or demagnetize selected cores.

The chief advantages of magnetic-core memories are that the ferrite cores can be mass produced very cheaply, and that we can easily gain access to the stored information through transistorized circuits. At present, there is a competition between magnetic-core memories and memory tubes. Many of our telephone engineers believe that the memory tube is a little faster and a little cheaper than the core memory, but they recognize that as further improvements are made in the art the situation may be likely to change.

Having seen how electronic memory systems will store thousands and even millions of bits of information, it is appropriate to consider mechanized logic. We have had logic circuits in the telephone plant for years — they are the circuits that deduce the logical results of the inputs to the circuits. As an example of logic, consider the plight of a fellow named Joe who belongs to a riding group. Every third day it's Joe's turn to drive to work. But things don't often work out that way because somebody is always having to take someone else's turn for one reason or another. Suppose that Joe comes home from work some evening and his wife says: "Honey, did you ask the fellows if one of them could drive for you tomorrow?"

Joe says, "Sure I asked them. When I asked Pete if he'd take my turn, he was just leaving for Philadelphia but he said he'd be glad to drive tomorrow if he didn't have to stay over in Philadelphia and his wife didn't need their car. Anyway, Oscar will probably be able to drive, because his wife has been staying home lately and he will drive her car, if she doesn't go to work. He also said that since his own car is due back from the garage tomorrow, he can drive it even if his wife does use hers provided the garage gets the car back to him. But if this cold of mine gets any worse I'm going to stay home even if those guys have to walk to work and you'd certainly have the car if I am going to be home."

To simplify all this, Joe might draw a logical block diagram like Figure 6 for his wife. The block diagram has an output, a signal present, whenever Joe will drive. It has signal inputs on the left. We have a signal present on the first lead, for example, if Peter's wife needs their car. The "or" circuit is called an "or" circuit because it will have an output whenever there is a signal on the top OR bottom lead. The "and" circuit will have an output if there is a signal on its top AND its bottom lead. The third type of circuit, called an INHIBITOR circuit, will have an output if there is a signal on the top lead, unless there is a signal on the bottom lead. Note that if Joe's cold is worse, the INHIBITOR functions and regardless of the signal on the top lead there will be no output because Joe just isn't going to drive if his cold is worse.

Joe could mechanize the circuit with either relays or transistors. With the use of transistors, the circuit could determine its output in a millionth of a second. In our telephone plant of the future, there will be an extensive use of transistors for the kind of logic functions that have in the past been performed with relays. Since the transistor can be made to operate in a millionth of a second, we can time-share these circuits and, like the chessmaster, reach very fast decisions.

So far we have explored the characteristics that put the magic in electronics. You have seen how we can mechanize functions which lead people to refer to electronic machines as electronic brains. By analogy with the chessmaster you saw how we might, through time sharing, build a new type of electronic switching plant. It is appropriate now to be more specific about the use of mechanized memory and logic in building this plant.

In new electronic switching systems which Bell Telephone Laboratories engineers are now planning, mechanized memory and logic circuits are time-shared to control a high-speed switching network. Extensive memory will be used in such switching systems. Information is stored in both temporary and permanent memories. The kind of information which might be stored in the temporary memory can be determined by going back to the chessmaster or telephone-master analogy. The telephone-master would store in the memory tube certain information regarding the lines coming into the office. Suppose the office is a 10,000 line office. The machine would look at each line and observe whether or not the receiver was off the hook and would then store in the memory a binary digit which answers the question, "Does the line corresponding to this memory cell want service or doesn't it?" The machine would also store for each line the answer to the question, "Is the line getting service?" If the answer is "yes" the machine would not worry about the line. If the answer is "no" the machine would then prepare to give the line service. If dial pulses are coming in over the line the machine will store in its memory the number of dial pulses received. Note that relay registers might have been provided to store the dial pulses. Instead, the memory is provided wholesale in a big economical memory system where the dial pulse information is stored along with the other information.

Because of these new system concepts and new apparatus such as the transistor and electronic memories, we can expect to see electronics as the basis of telephone switching as well as transmission. Because all functions are achieved by sequences of logic and memory operations, we expect our equipment to become more flexible. In the future the same equipment used to set up telephone calls may also be used to perform billing and accounting functions, to prepare service orders, and to do circuit layout engineering. At some stage in the future, we may have a telephone plant in which the boundaries between separate functions are not very distinct because the same machinery is carrying out all of our operations. Many engineers are confident that this is the way to simplify and to make cheaper the cost of doing the telephone job.

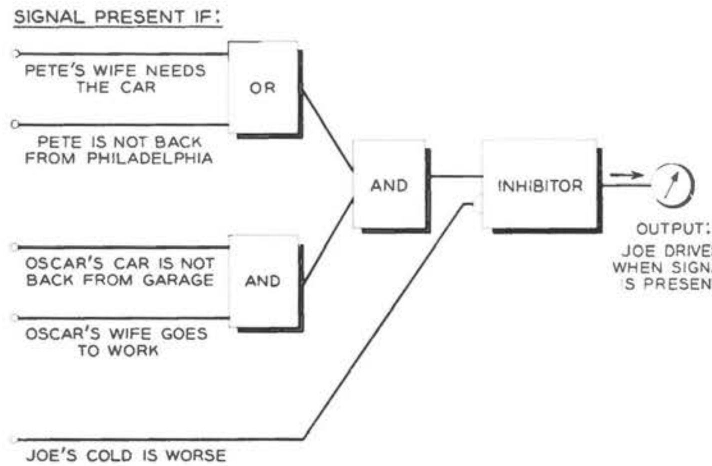

Fig. 6 — Block diagram illustrating logic behind answer to question, "Will Joe drive?"

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J. H. Felker attended Washington University in St. Louis, Missouri, and received the B.S. degree in Electrical Engineering in 1941. Mr. Felker served in the U. S. Army from 1942 to 1945, first as a radar maintenance officer and later as an Army publications officer. He joined the Laboratories in 1945, where, in the Military Systems Engineering Department, he was in charge of the development of the Tradic transistor digital computer. In 1955, Mr. Felker was appointed Director of the Special Systems Engineering II Department, where he is responsible for long range planning in data processing and transmission. He is a member of the Institute of Radio Engineers, and is past Chairman of that organization's Professional Group on Electronic Computers.