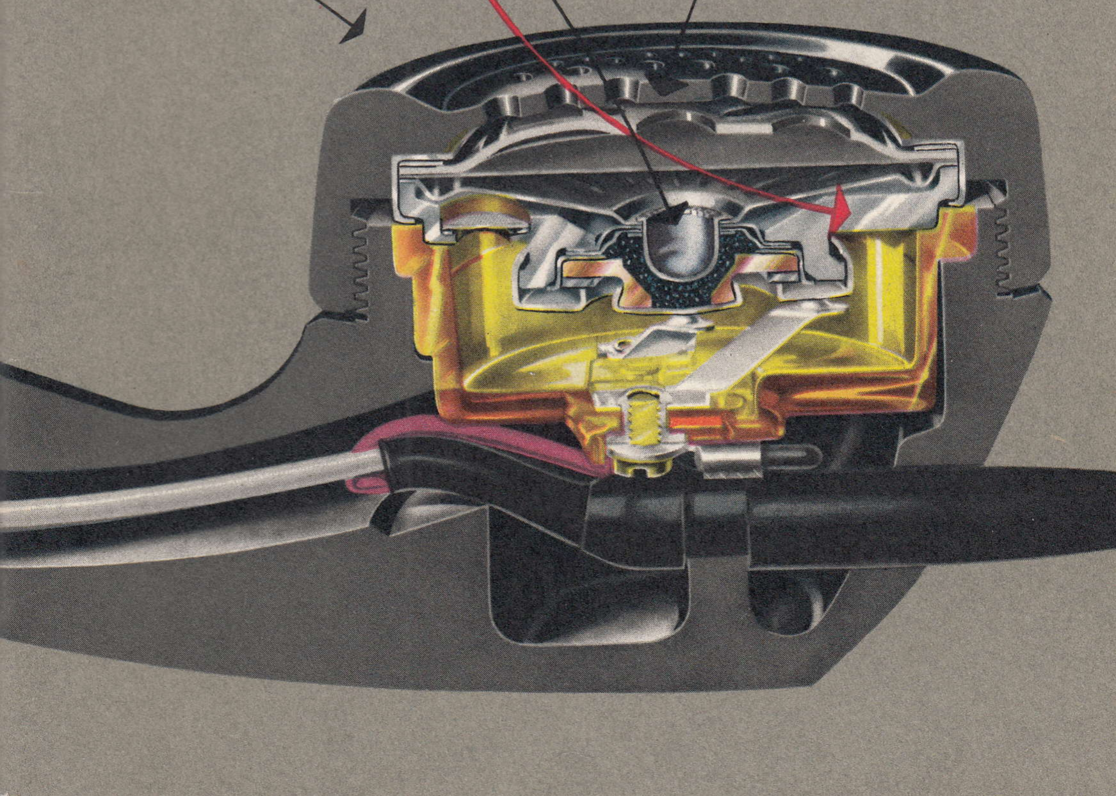
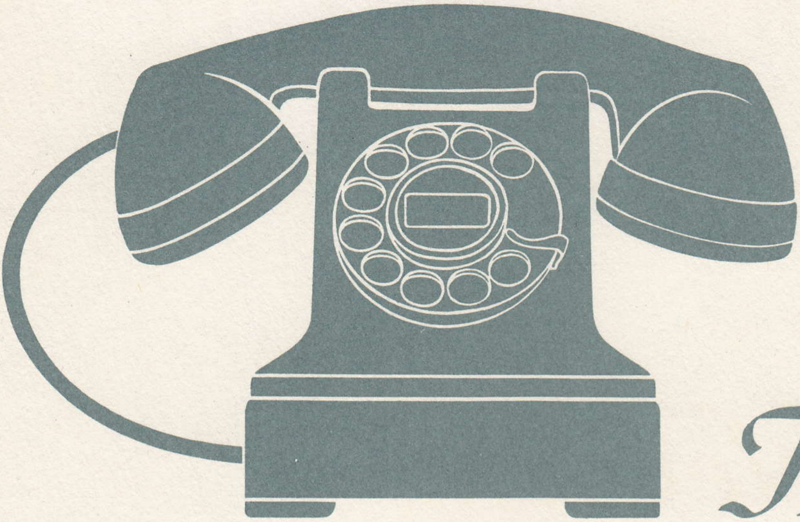
The Magic of Communication





The

BELL TELEPHONE SYSTEM 1953

Telephone

A Magic Device

The telephone is a marvelous device. It catches a spoken word and turns it like magic into something we can not see or hear that speeds along the wires or through space to another telephone. There the magic is undone and the hidden word comes forth, just as the enchantments cast upon living persons in the old fairy stories finally were broken by charms – and everyone lived happily ever after. Our modern fairy story is the story of electricity. The transmitter in your telephone casts a spell upon each word it catches, sending it noiselessly on its way. The receiver breaks the spell and a living word issues, bearing its message from a far-distant speaker.

THE TELEPHONE

Mechanical Vibrations

Your telephone *rings*. You answer it and the person calling *speaks* to you. As you converse you are faintly aware of the wind *howling* around the corner of your house and a street car *rumbling* past. Somewhere in the distance a train *whistles* and in another part of the house a door *slams*.

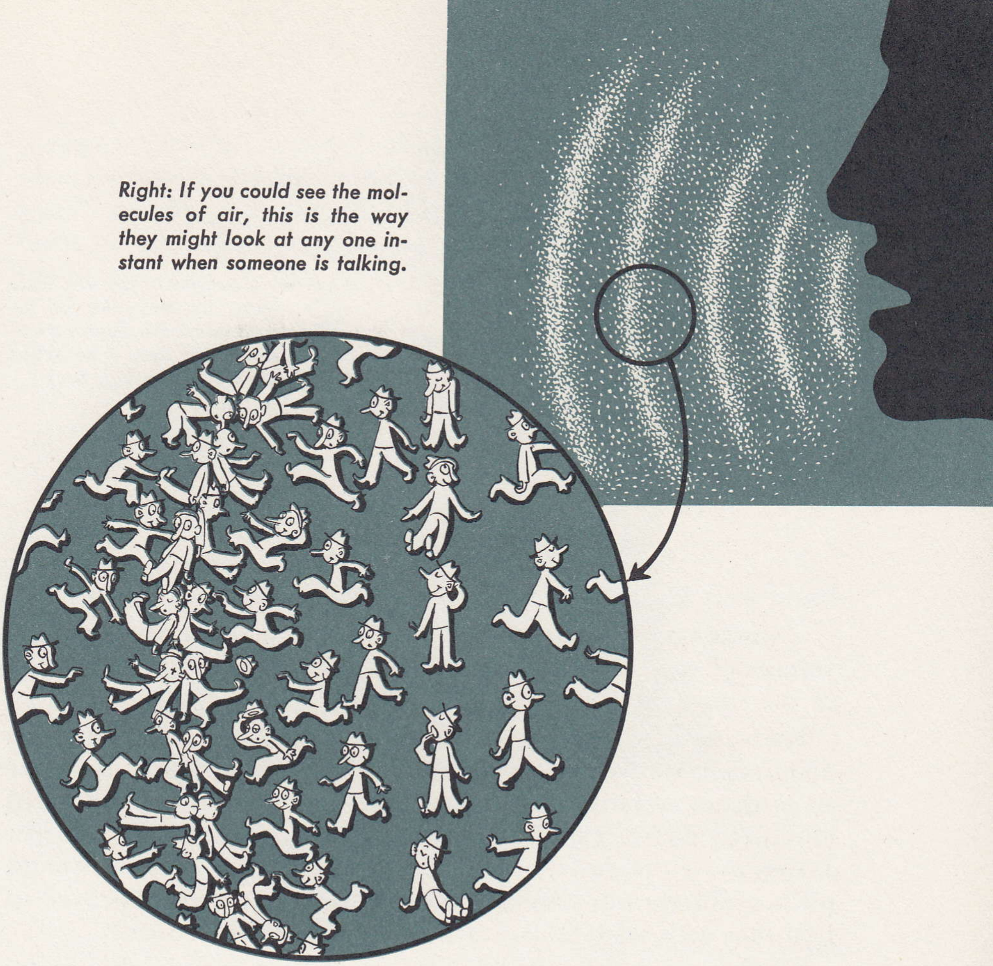
Those sounds are *vibrations* — mechanical vibrations — that set air waves to vibrating against your eardrum, which causes a message to be transmitted to your mind. Each of them has its own number of vibrations per second — that is called *frequency*.

The motion which you give to the molecules of air when you speak is not like that of the wind where a multitude of air molecules sweeps along. In a spoken word, or in any musical sound, the molecules dance back and forth. First they advance, pushing against the eardrum, and then they retire and the membrane of the ear springs back. Over and over again this happens, hundreds and even thousands of times every second. The higher pitched the voice of the speaker the higher the frequency and the more rapid is the dance. And yet it is a dainty dance, for the weight of a snip of human hair only about one-thousandth of an inch in length would press as heavily upon the sensitive eardrum.

Sound waves do not travel very far or very fast. Actually they poke along at only 1,075 feet per second and the farther they travel the more faint they become. But when their electrical counterparts travel, as in a telephone circuit, their speed may be increased as much as 900,000 times. Though they, too, weaken as they travel along, they may be amplified at intervals and repeated with practically the same clarity and tone as when they were spoken, no matter how far they have traveled.

Alexander Graham Bell was able to invent the telephone because as an expert in instructing the deaf, he had extensive knowledge both of vocal cord vibrations and of the operation of the human ear. His interest in the electrical transmission of speech grew naturally out of his broad knowledge of acoustics and his experiments with an invention intended to send several telegraph

Right: If you could see the molecules of air, this is the way they might look at any one instant when someone is talking.



messages at one time over a single wire. This "harmonic telegraph," as he called it, utilized strips of steel organ reeds mounted so that they would vibrate over electromagnets.

One day in 1875, while he and his young assistant, Thomas A. Watson, were adjusting these instruments, Watson gave one tight reed a pull with his finger and the reed on the instrument at the other end of the connecting wire reproduced the sound. When Bell heard this faint sound he knew at once that the speaking telephone of which he had dreamed was a possibility!

Bell knew that when he spoke, everything within sound of his voice vibrated in response to his vibrating vocal cords. He knew that as people talk, nearby books vibrate, chairs vibrate, walls, tables, pictures, lamps vibrate — but so slightly that such vibrations

When the molecules of air which are set in motion by the voice of the speaker rush against the diaphragm of the transmitter they bend it in. When they rush away it springs back.

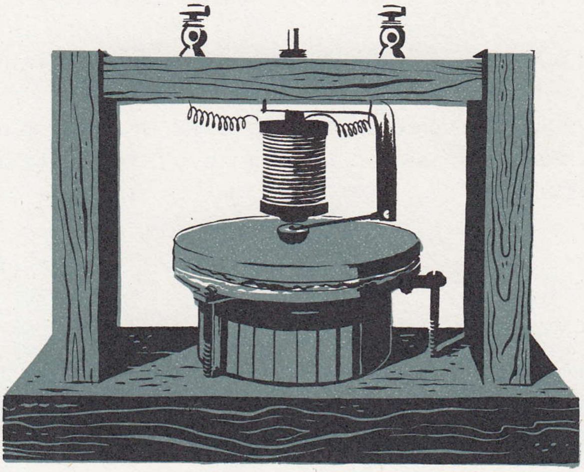
could only be measured by very sensitive laboratory equipment.

(Nowadays you can prove this to yourself by turning up the volume of your radio until the windows, dishes, and other objects in the room rattle.)

Knowing this, Bell reasoned correctly that a thin metal disk, or diaphragm, would vibrate as he talked against it, just as he knew an eardrum vibrates. The tiny particles, or molecules, of air, set in motion by the voice of the speaker, would move the diaphragm just as they move the eardrum in direct proportion to the intensity and pitch of the various sounds. And the twang of that reed proved to Bell that such vibrations could be transmitted electrically.

So that June evening in 1875 he had Watson fasten a thin metal diaphragm of magnetic material to a small drum head, and back of it place an electromagnet, which is a soft iron core with wire wound around it. He reasoned that as the diaphragm vibrated back and forth in response to the vibrations of his voice, it moved first toward the magnet, then away from it. This would induce a current to flow in the coil of wire around the magnet, first in one direction as the diaphragm moved in and then in the opposite direction as the diaphragm moved out. The coil of the magnet was connected by a wire to a similar instrument at the other end of the line. Thus the wire would carry electrical currents of varying intensity substantially identical with the varying vibrations of the diaphragm.

Just as he expected, these varying currents, flowing over the wire and around the electromagnet in the other instrument, caused the magnet to pull its "receiver" diaphragm back and forth in accordance with the direction of current flow. This disk, vibrating identically with the disk in the sending instrument, repeated Bell's speech sounds. After months of further experimenting and refinement he created an instrument that transmitted the first intelligible sentence, on March 10, 1876.



Bell's first telephone (1875). It transmitted and repeated speech sounds but not words.

Electrical Vibrations

The discovery made by Bell which led to his invention of the telephone was that waves of electricity can be created that have the same pattern as the waves of air you set in motion when you speak.

Just *how* the telephone manages to do this was better understood after the electron was isolated by the English physicist Sir J. J. Thomson, in 1897. For twenty years the telephone had been changing mechanical vibrations into electrical vibrations and vice versa, but the way in which it performed this magic had been something of a mystery.

We, too, may comprehend it better if we take a brief look at the tiny but mighty electron.

Electrons have been defined as tiny particles of electricity, all absolutely alike, each about one eighteen-hundredths (1/1848) as massive as the lightest atom. This electrical particle is a building block which nature has used in the construction of the atom. The tiny electron is an irreducible minimum of electricity, but of a particular kind, called negative.

Being all negative, electrons strongly oppose one another. This repelling force among electrons is relatively enormous. Also, they exist everywhere. The air you breathe, the chair you are seated on, your clothes, this booklet, *everything* is permeated with electrons. Quite a number of them are "free," that is, they are not attached to any particular atom. So long as these free electrons have relatively little motion they are of slight use or interest to us. But greatly increase their motion and their potential power far exceeds our comprehension.

The variations in the current through a telephone transmitter look like this when the words "Bell Telephone" are spoken into it.

In telephony, the electrons in the windings of the magnetic coils and in the wires connecting the instruments are energized, or caused to move, by introducing a battery in the circuit. A chemical action then results which compels the electrons to move out of the battery, around the windings of the magnets in the telephones, and so on back into the battery. We can control this flow of electrons around the circuit, just as we can control the amount of water flowing through a pipe, by means of some sort of valve.

The telephone transmitter is, in effect, such a "valve." Its function is to change the steady procession of electrons around the circuit into a dance or vibration. This dance of the electrons must be exactly the same as the dance of the molecules of air against the diaphragm of the transmitter.

Let's see how this is accomplished.

The Telephone Transmitter

Bell's first telephones were a far cry from the sensitive yet durable instruments we use today. The same instrument was used both as transmitter and receiver by holding it up to the mouth when speaking and to the ear when listening.

In the early days the speaker caused the diaphragm of the transmitter to vibrate by sheer lung power. In order to get the rugged drum head to quiver he had to increase the volume of his voice just as you have to turn up the volume of your radio to make the dishes rattle.

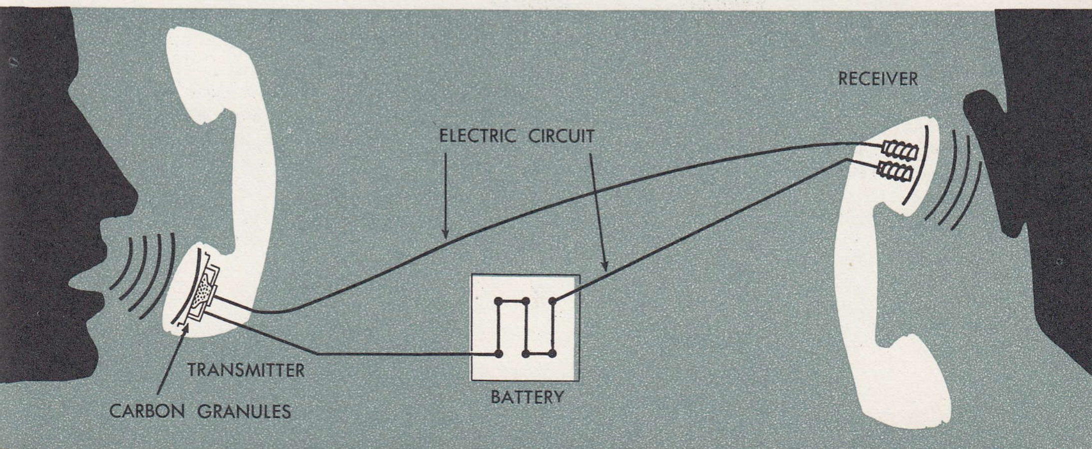
Though the basic principles that led to the first telephone still apply, the instrument itself has undergone many changes. Through the years there has been a steady evolution in both its appearance and its mechanical construction.

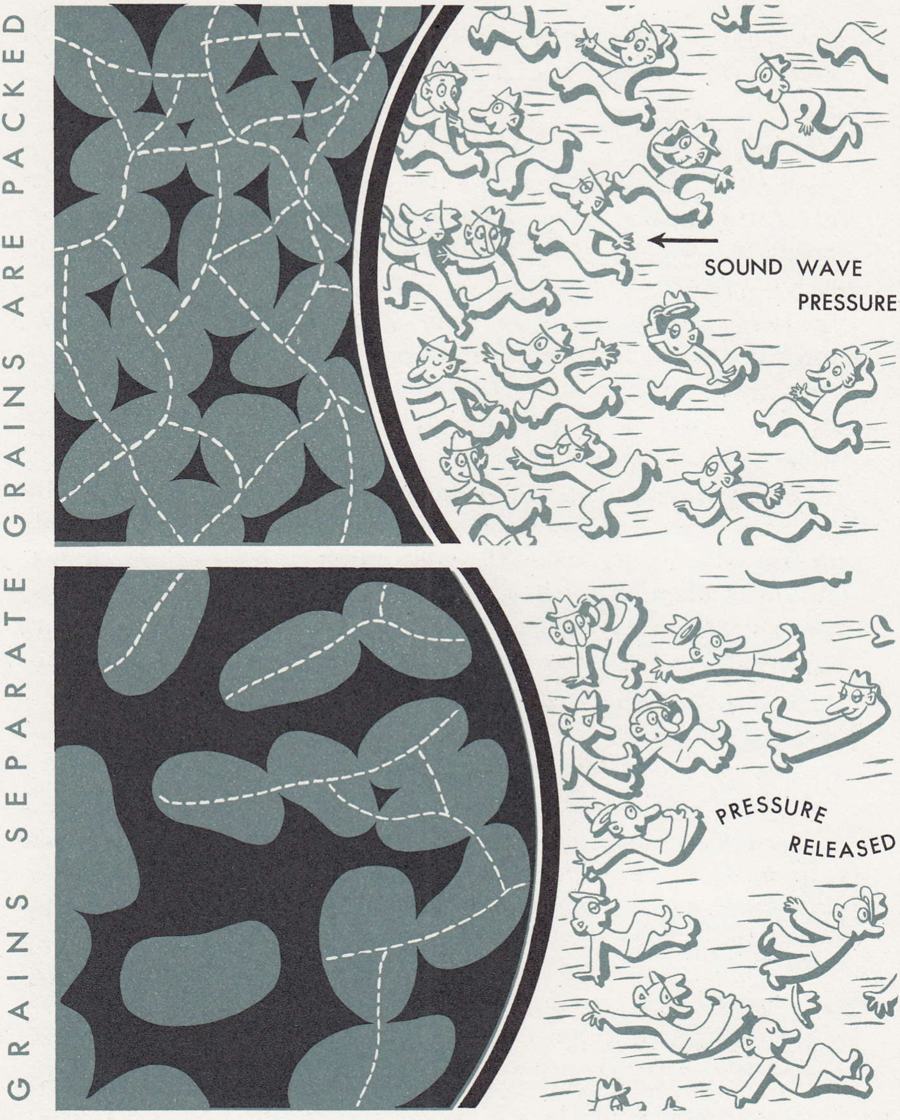
The telephone transmitter of today is a sensitive electric ear. Fastened to the back of its eardrum (diaphragm) is a chamber filled with an exactly measured quantity of carbon granules — grains of roasted coal. Through this carbon chamber and the connecting wires a battery sends an electric current.

Under the steady urge of the battery, billions of electrons march in procession from grain to grain of carbon and through the wires, around and around the circuit.

As the diaphragm is moved back and forth ever so slightly by the dancing molecules of air, the carbon grains behind it are packed

This chart shows a simple telephone circuit with a battery introduced to cause billions of electrons to march in procession around the circuit.





Carbon grains in a transmitter magnified about 50 times each way. When sound wave pressure bends the diaphragm in (above) the grains are closely packed and many electrons can pass through. But when the pressure is released and the diaphragm springs back (below) the grains are loosely packed and fewer electrons can pass from grain to grain.

more closely and then less closely. Over and over this happens, as often as the transmitter diaphragm vibrates back and forth.

Imagine a vast army of men crossing a lake on floating blocks of ice while the wind freshens and dies alternately.

When the blocks are blown close together crossing is easier, and more men get across than when the blocks are loosely packed.

This, on an enormously increased scale, is a picture of what happens when electrons cross from grain to grain in the carbon of the transmitter. Men can move only slowly, but the tiny electrons move at the terrific pace of thousands of miles a second.

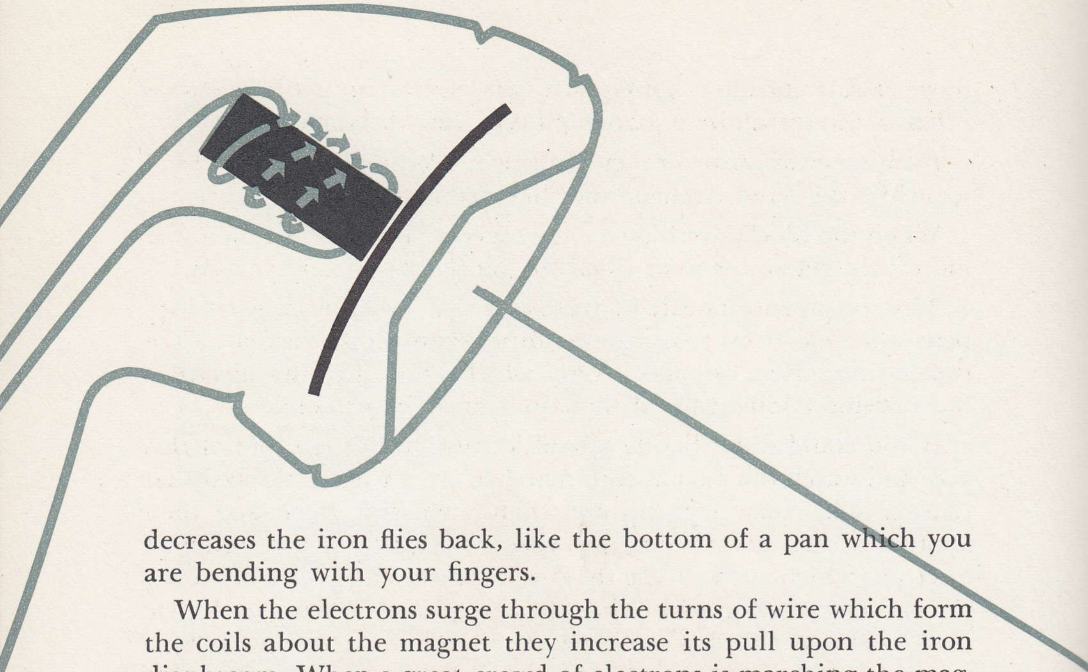
If you could stand beside a road leading from the shore of this lake and watch the men as they marched past, you would find that there would come a group and then some stragglers; and then another group, and so on. It is the same with the procession of electrons which moves along the wire from the chamber containing the packed carbon grains. When there are many, we say the electric current is larger than when there are few. So the current changes, increasing and decreasing alternately, as the diaphragm compresses the carbon more or less.

The Telephone Receiver

These varying electrical currents go dancing along the telephone wire until they reach the receiver at the other end of the telephone hook-up. Now the problem is reversed. How can this electrical energy be transformed back into speech sounds?

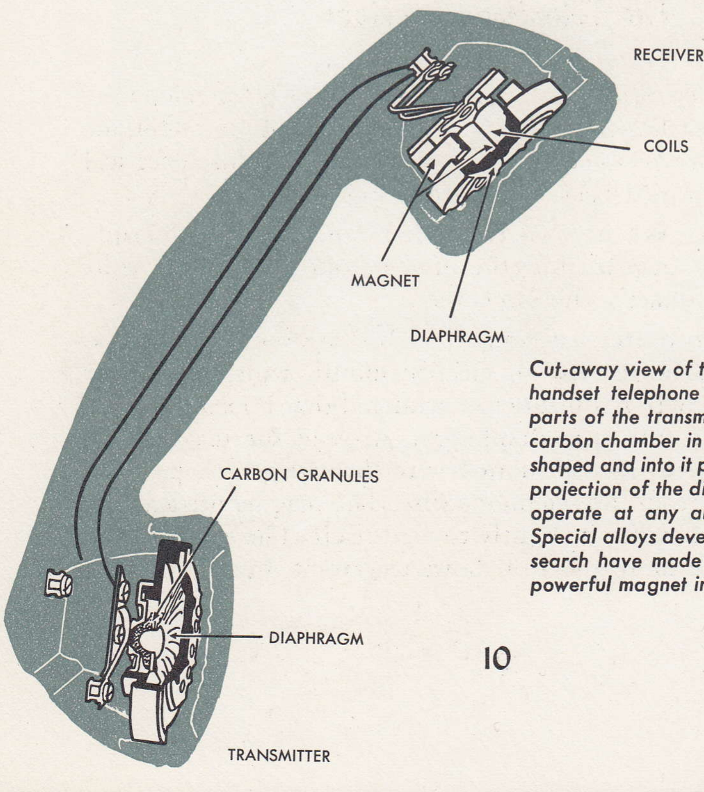
This is simple. We have already seen how Bell's first crude receivers worked. In principle, the modern one attached to your telephone works exactly the same way.

Just as the transmitter has been described as an electric ear, so the receiver may be termed an electric mouth which can utter human sounds. There is a magnet so arranged that it exerts a force of attraction on a thin iron diaphragm. Around the magnet is a winding of many turns of insulated wire through which pass the varying currents from the telephone line. The magnet attracts the iron diaphragm, bowing it slightly toward itself. The stronger the magnet pulls, the more the iron bows toward it, but if the pull



decreases the iron flies back, like the bottom of a pan which you are bending with your fingers.

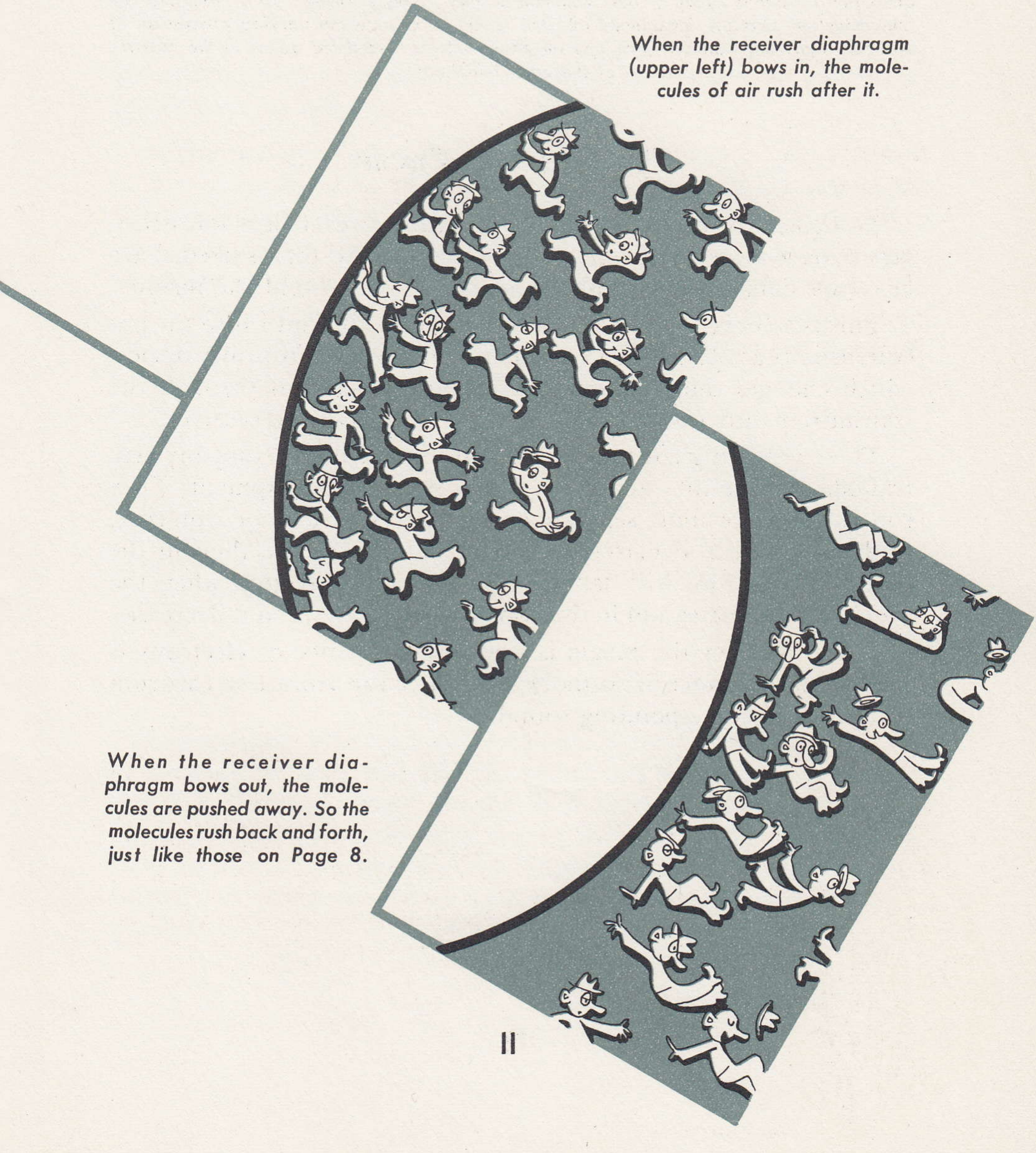
When the electrons surge through the turns of wire which form the coils about the magnet they increase its pull upon the iron diaphragm. When a great crowd of electrons is marching the magnet pulls harder; but when only stragglers come the bent diaphragm springs back.



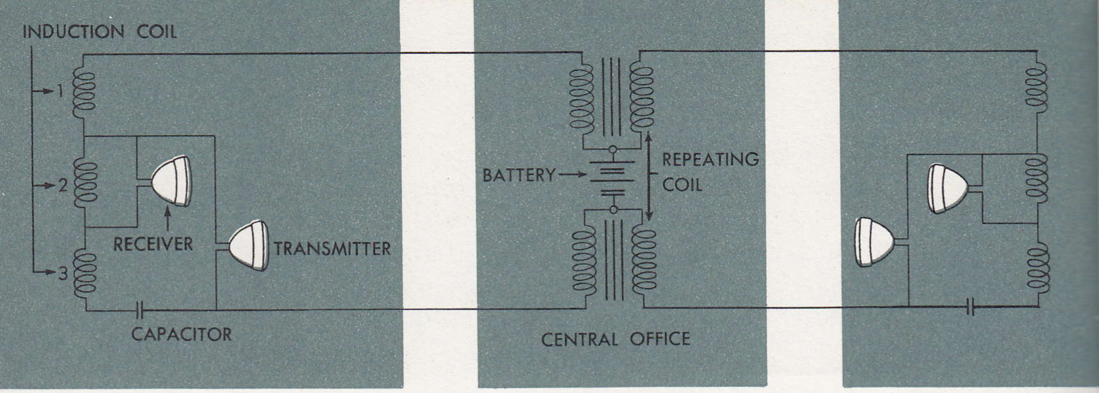
Cut-away view of the handle of a modern handset telephone showing the principal parts of the transmitter and receiver. The carbon chamber in the transmitter is bowl shaped and into it protrudes a thimble-like projection of the diaphragm so that it will operate at any angle its user holds it. Special alloys developed by telephone research have made possible the small but powerful magnet in the compact receiver.

The motion of the diaphragm of the receiver is just the same as that of the diaphragm of the distant transmitter. And the air molecules near the receiver are set into the same kind of motion as those which danced against the transmitter diaphragm. That is why the receiver speaks, undoing the magic which turned a spoken word into an irregular procession of electrons.

When the receiver diaphragm (upper left) bows in, the molecules of air rush after it.



When the receiver diaphragm bows out, the molecules are pushed away. So the molecules rush back and forth, just like those on Page 8.



Simplified telephone circuit of the "common battery" type, showing how a repeating coil and induction coils are introduced into the circuit to change the varying procession of electrons from the transmitter of one telephone into a to-and-fro dance in the receiver of the other telephone.

The Telephone Circuit

To make a receiver diaphragm vibrate, however, it is not necessary to have a varying procession of electrons. All that is needed are electrons dancing back and forth in the coils around the magnet.

This is achieved by the introduction of another unit into the circuit, usually a *repeating coil* or other equivalent transformer device, which changes the irregular procession of electrons through the transmitter into a to-and-fro dance in the coils of the receiver.

These repeating coils are located in the telephone company central office where they are a part of the switching equipment. They consist of two or more separate coils wound on the same iron core. If through one coil marches an irregular procession, then in the other the electrons will dance, moving in one direction when the procession increases and in the opposite direction when it decreases.

In the receiver the magic is undone; the dance of electrons is changed into a dance of air molecules which can vibrate an eardrum and produce corresponding sounds.

THE CENTRAL OFFICE

Telephone Doorways

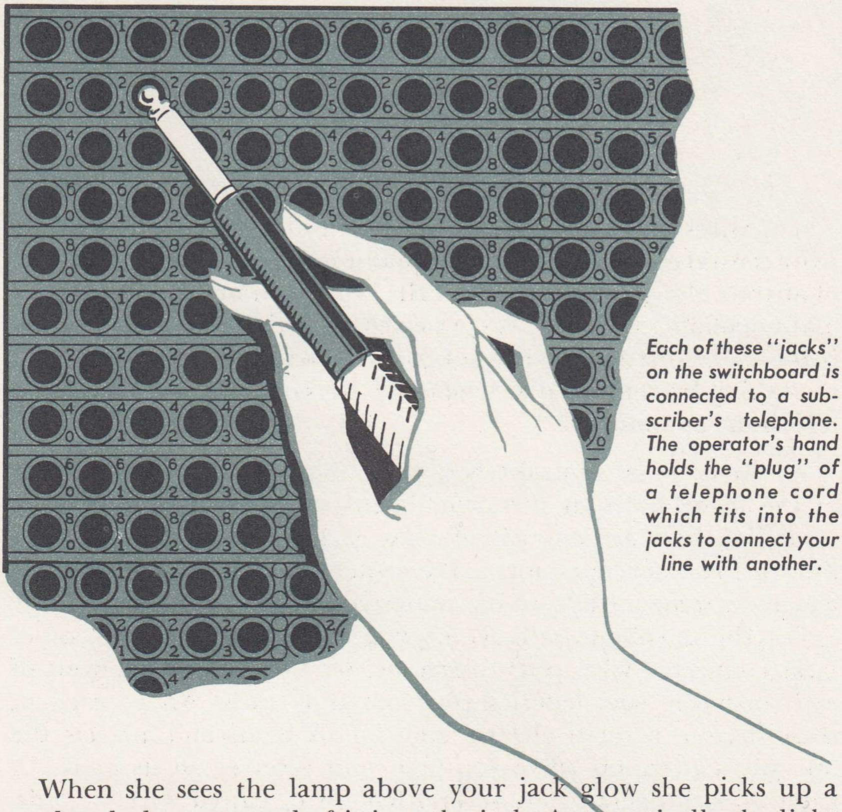
The wires attached to your telephone lead to the telephone company central office. Here, your telephone can be connected with that of anyone else you may wish to call. When you make a call from a dial telephone, your line is connected with the line of the person being called by ingeniously-designed electrical equipment. If you are calling from a non-dial telephone, the connection is made by a telephone operator.

At the non-dial central office, your line ends in a "jack" – one of the many holes in the switchboard in front of the operator. Actually, there are enough of these jacks hooked up with your line so that each operator at the switchboard can plug into one whenever someone asks to be connected to your telephone.

For the telephone calls which you make, there are still other jacks connected with your telephone. One of them is in front of each operator who handles your outgoing calls. Above each of these jacks is a small electric lamp. This lights and attracts the operator's attention when you take your receiver off its hook. In front of each operator are several lengths of paired wire – cords, as they are called. By using one of these the operator who answers your call can connect you directly to the line of anyone else whose telephone is served by that switchboard, or she can plug into a line leading to another switchboard.

"Number Please"

The operator wears her telephone set. This leaves her hands free to handle the cords and also the numerous little switches, which she calls "listening keys," on the shelf before her. Her own telephone can be connected with any of the cords, but it is shut off from each cord by a separate key. All these keys or switches remain turned off unless she moves one and then holds it in the "on" position.



Each of these "jacks" on the switchboard is connected to a subscriber's telephone. The operator's hand holds the "plug" of a telephone cord which fits into the jacks to connect your line with another.

When she sees the lamp above your jack glow she picks up a cord and plugs one end of it into the jack. Automatically the light goes out. With her other hand she then moves the key which connects her telephone with the cord she is using and so is able to answer you.

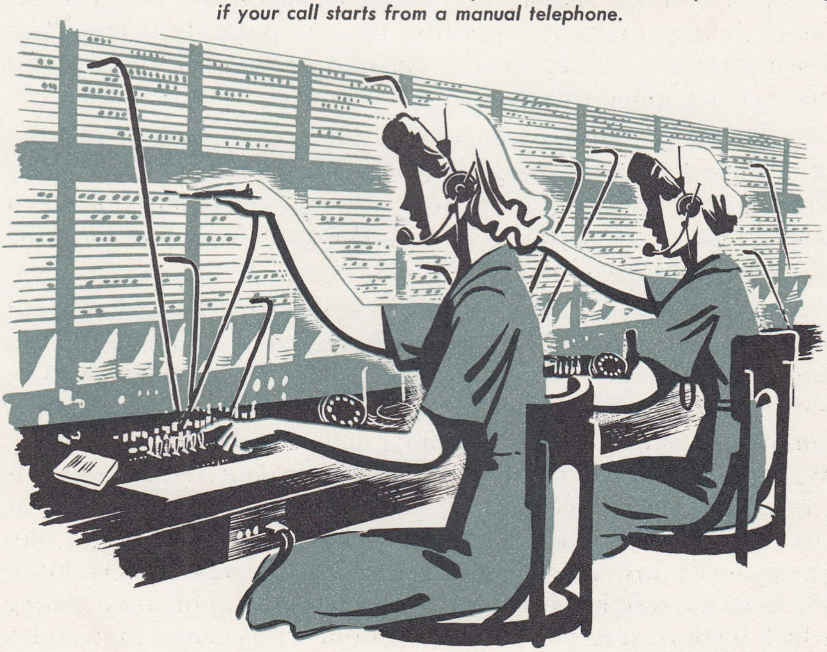
If you live in a city which has just one telephone office and all the calls are handled by operators, every subscriber in that city has a jack within reach of your operator. These jacks are arranged in numerical order on panels in front of her. If, then, your call is to someone in that city it takes her only an instant to plug the other end of the cord into the proper jack and send a ring down that line to call the other person to his telephone.

A signal lamp, close to the cord the operator is using, lights when she plugs into the jack of the telephone you are calling. It stays lighted until your party takes his receiver off its hook; so she knows at a glance whether or not he has answered your call.

If the telephone you are calling is busy the operator must know it to avoid interrupting. Special devices help her. She tests the telephone line of the person you want to reach before plugging in. With the tip of the plug she touches the jack. If his line is busy, she knows it instantly, for she hears a clicking sound in her telephone. If she doesn't hear this warning, she pushes the plug all the way into the jack and rings to call him.

The city in which you live may be served by two or more central offices. If the person whom you are calling is in a district served by another telephone office your talk must follow a trunk line to that office. So your operator tests the trunks to the particular central office until she finds one that is not in use. Then she inserts the plug into this jack. In a moment a sound tells her that the operator at the other end of the trunk in the other central office is ready to make the connection. Then your operator gives the number and the other operator connects the trunk with the line of the person you want.

Operators like these complete the connection for you to the number that you are calling if your call starts from a manual telephone.



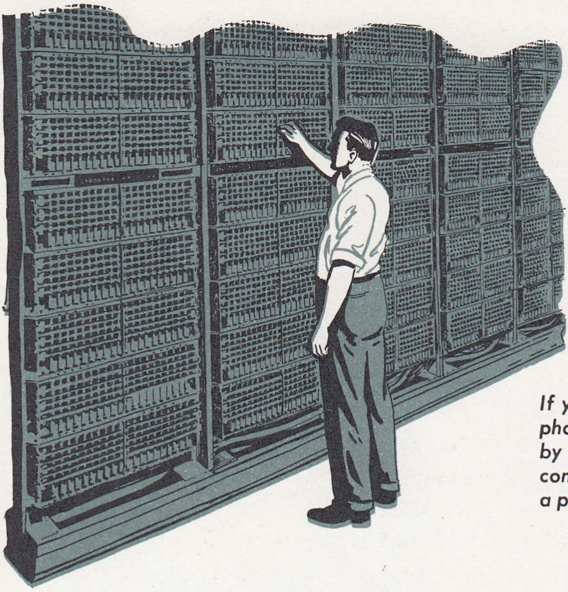
"Hum-m-m-m-m-m-m-m" Goes the Dial Tone

What the operator does by hand must be done by machinery if your call starts from a dial telephone. This electrical equipment is very complex; that is, it has a great many parts. The parts themselves really are simple mechanisms, but they are so precisely designed and so ingeniously arranged to work together that they quickly and accurately follow the instructions which you send to them when you dial your telephone.

In the machine-switching equipment of a dial telephone central office there are several kinds of parts, but the most important is the electromagnet. This gives a pull when a current passes through its winding. That pull can be used for almost any purpose. It can close a switch so as to send current into other electromagnets and so make them work. Or; the pull can be used to close contacts between circuits, or to move some other piece of equipment, sliding it along a little way, or giving it part of a turn if it is something which rotates. An electromagnet, for example, can be set to push some piece of apparatus along, moving it a certain distance each time a current is sent through the magnet winding. For each pulse of current which reaches the electromagnet, the apparatus can be made to move another step along whatever path its designers wish it to take.

Dial switching equipment must be able to handle a large number of telephone lines and do a lot of different things. In the first place, for example, the equipment must find your telephone line when you lift your receiver off its hook, picking out your line from the thousands which end in the same office.

You remember how the operator does this when the switchboard is manual instead of mechanical in its operation. She is guided to your line by a lamp which lights as your receiver is raised. The electrical mechanism, having no eyes, would not be aided by a lamp; it must hunt in the dark and it does so by feeling electrically. When your receiver is raised the switch in your telephone set is closed, and current flows along your line from a large battery at the central office. At that office a switching mechanism is put into operation by this sudden flow of current. The apparatus starts hunting over the terminals of a relatively small group of lines, among which is yours. It stops when it feels a line with current in it, and is then ready to do what you want.



If your call starts from a dial telephone intricate switches actuated by electromagnets complete the connection for you. Shown here is a portion of a frame of "crossbar" switches in a dial office.

The girl operator would ask you "Number please?" The mechanism can not talk, so it sends you a tone to say it is ready for your instructions. And since it can not hear, you dial the number.

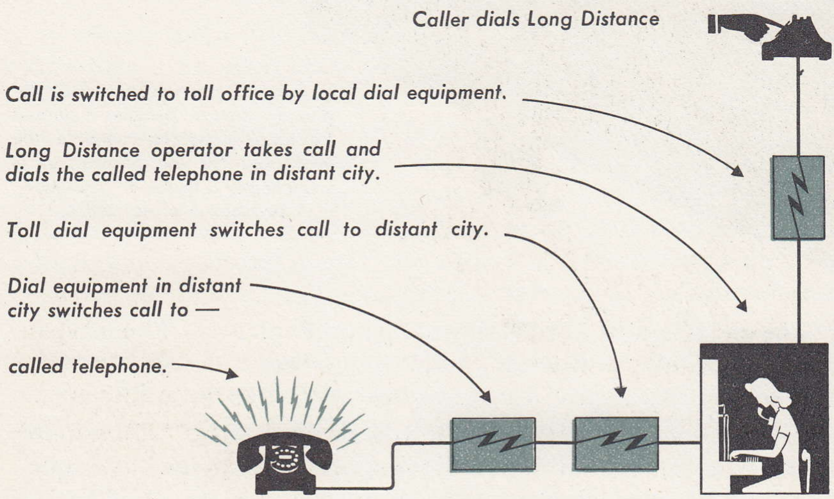
It is extremely important that you listen for this "Hum-m-m" before you start to dial. If you dial *before* you hear the "dial tone" you'll get a wrong number or no number at all.

As the dial rotates back to its original position there is a click for each unit of the digit you dialed – three clicks for 3, four for 4, and so on. With each click a pulse of current passes through some electromagnet in the mechanism at the central office. That mechanism then proceeds to put the call through for you. Each of its actions is simple, but taken all together they are very complicated, and a vast amount of equipment is needed.

Dialing Long Distance Calls

Bell System long distance operators in hundreds of cities and towns can now dial calls straight through to distant telephones without the assistance of other operators along the route or at the distant places. Even calls across the continent are dialed in this manner between many cities on the Atlantic and Pacific coasts.

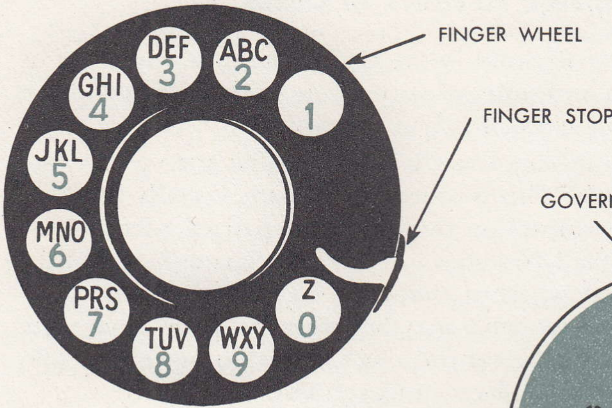
The new equipment and methods that make operator toll dialing possible are rapidly being placed in service throughout the country. Eventually it will be possible for long distance operators everywhere to dial calls directly to any telephone connected to the toll network. Two out of every five of the Bell System's long distance calls now are handled this way.



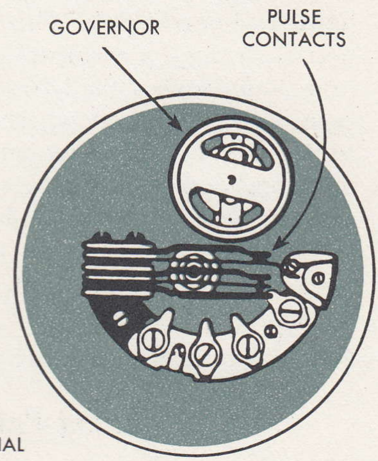
In addition, equipment in several areas now enables telephone customers to dial their own calls directly to nearby cities or communities beyond their local calling areas in the same way that they dial local calls. An installation now in use at Englewood, New Jersey, makes it possible for some 10,000 telephone users there to dial their own long distance calls to any of 11,000,000 telephones in and around a dozen cities from coast to coast.

This new equipment, developed by Bell Telephone Laboratories, employs an electrical "brain" to receive the dialed number and complete the call, while an automatic message accounting system gathers the information necessary for billing. This "brain" will even make a second attempt if trouble is encountered on the call and at the same time punch on a card the details of the trouble so that the proper adjustments can be made promptly.

Additional facilities are being installed that will further extend the dialing of out-of-town calls both by operators and telephone users.

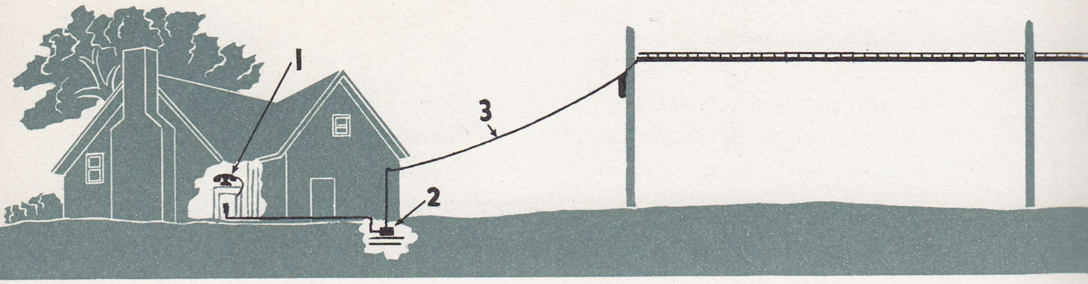


FRONT OF DIAL



REAR OF DIAL

Each click of the telephone dial, as it spins back to its starting position, sends a pulse of current through some electromagnet in the central office equipment.



HIGHWAYS OF SPEECH

Speech Avenues In Cities

The vast telephone network in the United States is woven out of millions and millions of miles of wire. Some of this wire you have seen many times but most of it is underground.

Probably most familiar to you is the wire that runs from your house to a nearby pole. This is called a *drop wire.* Usually it is connected through a terminal on the pole to a pair of wires which branch out from a small *distribution cable,* which runs from pole to pole back to a point where it branched off from a much larger *feeder cable.* This feeder cable may be strung on poles from your neighborhood back to the central office. Usually, however, especially in large cities, it is placed underground in conduit.

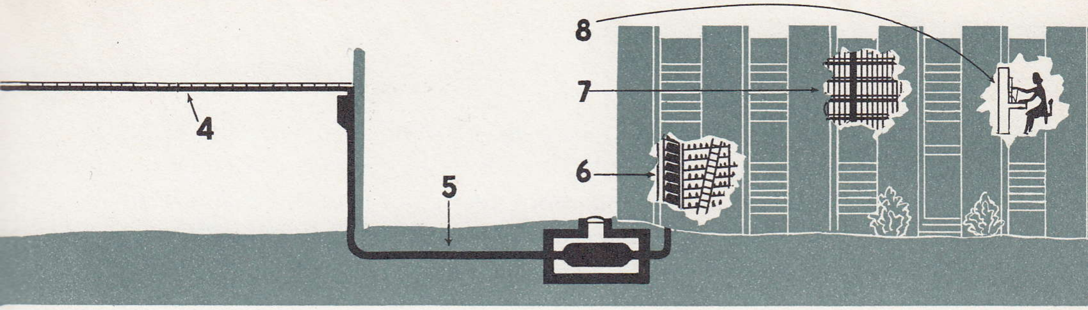
Trunk cables, which link together the various central offices in a large city, also are generally placed underground in conduit.

At present, over 95 per cent of all telephone wire in the Bell System is in cable and more than 60 per cent of it is underground.

Talking Paths In The Country

In rural areas open wire telephone lines usually run from farm to farm along country roads. These wires are many times thicker than the very thin individual wires in cables and are strung on glass insulators affixed to poles or on cross arms bolted to poles. Nowadays, thanks to the development of a high-strength steel wire that will permit longer spans, it is possible to space the poles twice as far apart as we have been used to seeing them. A light-weight cable carrying up to 26 telephone lines also has been perfected which permits spacing poles 500 to 600 feet apart.

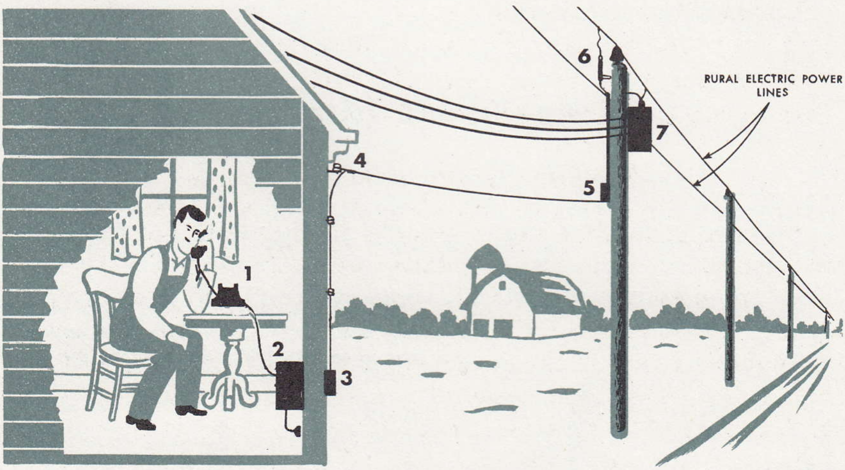
Other important new techniques and fast, economical construction methods are helping to speed the extension and improvement



(1) Your telephone; (2) protector, which guards against lightning and other high voltage charges; (3) drop wire; (4) distribution cable; (5) feeder cable; (6) distributing frame; (7) dial switching equipment; (8) Long Distance, Information, and Dial Assistance operators.

of telephone service in rural areas. Power-driven augers quickly drill pole holes. An ingenious type of plow, drawn through the earth by a truck, deposits rubber-insulated telephone wire directly in the ground and covers it, in a single operation. The same poles are being used to carry both electric power and telephone wires in thinly settled rural areas.

Ways have been found, too, to make telephone voice currents "hitch a ride" on rural electric power lines. This development is known as "power line carrier," and it means that many electric power wires can be used simultaneously for power service and for telephone service. (More about "carrier" is on succeeding pages.)



Equipment installed to provide service for a rural subscriber by means of power line carrier: (1) telephone; (2) terminal; (3) protector; (4) telephone drop wire; (5) unit containing safety switch and protector; (6) condenser which lets the telephone current through from power line to telephone and blocks the power current; (7) power transformer.

Radio telephony has been used for a number of years to bring service to remote rural areas.

Aided by these means, telephone service in rural areas has been growing and improving at a record-breaking rate. A larger proportion of the farmers in the United States have telephones than in any other country. New telephones are being added in rural areas at the rate of 1,000 each working day.

Trunk Highways Between Cities

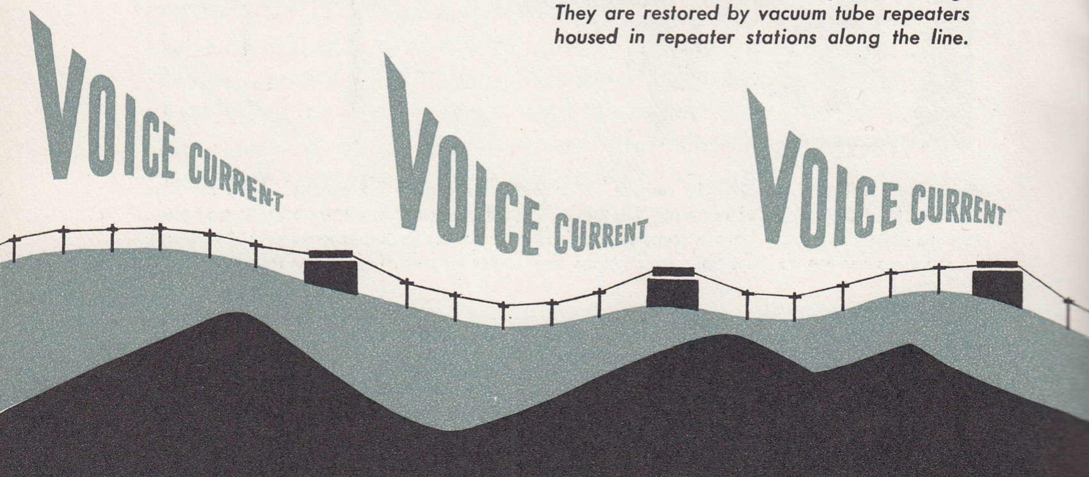
Intercity speech highways take several forms. Among these are the familiar open wire and aerial cable lines suspended on telephone poles, but more and more of the lines are going underground. Already there are thousands of miles of buried cable, much of it plowed into the ground in the same manner as buried rural lines but with huge specially-designed plows pulled by powerful tractors.

Toll cables also cross rivers and bays, and even go from the mainland to islands which are not too far away. Several such cables have been placed on the ocean's floor from Key West, Florida to Havana, Cuba, a distance of 115 miles. These are called submarine cables. Sometimes such water barriers are bridged by radio circuits, but more about that later.

Long Distance Telephony

On telephone lines the spoken word travels so fast that only by comparison can we realize its enormous speed. From New York to San Francisco, for example, a word can fly by telephone in a

Voice currents weaken as they travel along. They are restored by vacuum tube repeaters housed in repeater stations along the line.



fraction of a second — almost as fast as light travels. Compare that speed with the speed of sound traveling in air. If you ever happened to watch a baseball game from some distance away, or perhaps even from the center field bleachers of a large baseball field, you know the relative speeds of light (which is an electromagnetic phenomenon) and of sound in air (which is mechanical). You have seen the batter hit, drop his bat, and start for "first" before the crack of the bat reached your ears. A telephone line can carry a spoken sound from Minneapolis to New Orleans in far less time than it would take for a word to pass from catcher to second baseman across a diamond.

Between cities telephone *repeaters* are installed, the devices which make it practicable to telephone over long distances.

At each repeater station along the route a new group of electrons is set in motion. Just why we shall now see.

More Energy For Dancing Electrons

Along the wires which form a speech highway, the electrons pick up the dance one from another, first those in the coil of the transformer and then those farther and farther away. Just an instant and all along the line the dance is on. Back and forth they go, once for every vibration of the transmitter diaphragm.

It is work to get electrons dancing even though they are so very tiny. And those nearer the beginning of the line must do the work of starting others farther away. The ability to do this work is used up along the line and there are fewer and fewer electrons engaged in the dance. If the line is very long there may be so few dancing at the distant end that the receiver diaphragm either will not respond or will reproduce the speech too feebly to be understood.

Somewhere along the line, therefore, the electrons must be given more ability to do their work, more energy, as it is said. And that must be done without changing the step of the dance, because the speech is hidden in it and would lose naturalness or even sense. The device which can supply this energy is a *repeater,* for it starts a new group of electrons dancing but repeating old figures. It is connected at a repeater station to the end of one section of the speech highway and to the beginning of the next.

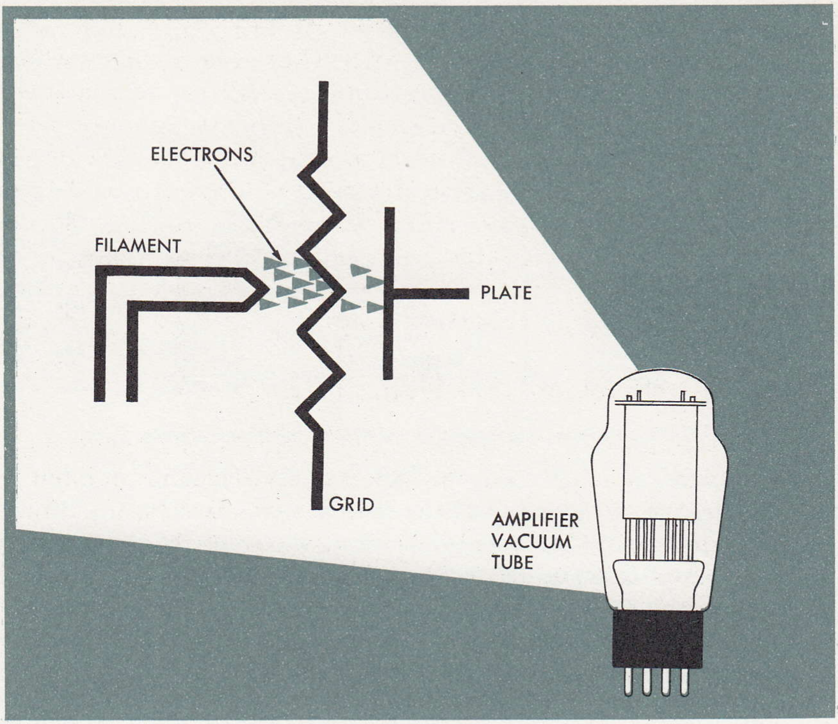
Between the transmitter and the receiver in a long distance telephone circuit there may be one to several hundred repeaters which make more electrons join the dance. These three instruments—transmitter, repeater, and receiver—are the most interesting devices in the story of electrical communication. But they are only a part of the very complicated arrangement of apparatus and lines which the telephone engineers have learned how to design and to operate. Several different kinds of telephone repeaters have been developed in the laboratories of the telephone company. The one now used is called a vacuum tube amplifier.

Modern Aladdin's Lamp

The vacuum tube is a wonderful device in which a few dancing electrons can control a great procession of other electrons. There is a glass tube, like a lamp bulb, from which the air has been pumped as thoroughly as possible. Within it is a filament which is heated dull red by current from a battery. The heat drives some electrons out of the filament into the vacuum. Then there is a metal plate which is connected to another battery; and this battery forms the electrons into a procession which shoots through the vacuum between the filament and plate and then marches around one coil of a transformer. The other coil is connected to the beginning of the *outward bound* line. If the procession can be made to vary, a dance will be started along that highway. The energy for the procession, and hence for the dance, comes from the two batteries.

Between the plate and the filament is a wire grid which is connected to the *incoming* section of line. The electrons of this line dance in and out of the grid. They have an enormous effect on the procession, making it much smaller when they dance in and larger when they dance out. So the procession is caused to increase and decrease in number just as does the original procession through the transmitter, where the talking is being done. On the other side of the transformer, therefore on the outward bound line, a new dance starts, just like the old but greatly amplified, that is, increased in numbers.

A repeater of this kind, using two amplifiers, one of which repeats in one direction and the others in the opposite direction, is used at each repeater station. But just how they are connected to the line would take too long to explain here.

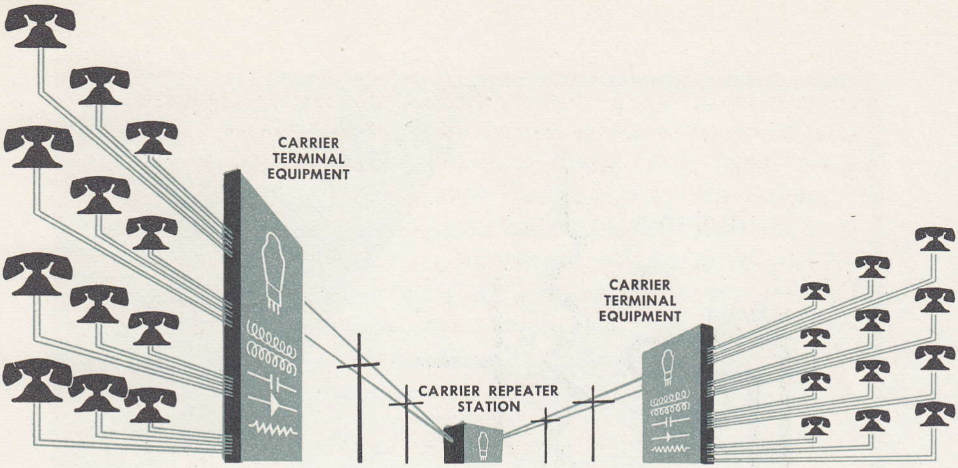


Schematic drawing of a telephone repeater vacuum tube and the principal elements in it.

The Miracle of "Carrier"

These wonderful vacuum tubes make many of the marvels of modern communication possible. For example, vacuum tubes are often arranged in long distance telephone circuits in such a way that a single pair of wires can be made to carry several different messages at the same time.

For the sake of understanding more easily how this is done, let's consider these arrangements of vacuum tubes as a number of different radio transmitting stations. Each of these "stations" transmits a distinctive high-frequency "carrier" current on the same pair of wires. Thus the wire is made to serve just like the free space through which radio makes its way, but in this case directs transmission very definitely from the transmitter to a particular receiver.



Visualization of a multi-channel carrier telephone system.

To do this it is necessary to have exactly the same number of "receiving sets" at one end of the pair of wires as there are "transmitting stations" at the other end. Along the route, of course, there must be amplifiers just as on any other long line. Because of these amplifiers the transmitters themselves can be much less powerful than radio transmitters and much smaller so that many may be grouped together in a space of a few cubic feet.

The "carrier" frequency sent along the wire by each "transmitting station" can carry a message at the same time that others are doing so, and at the carrier-terminals the different messages are sorted out by the "receiving sets" (other vacuum tubes) and each is sent to its proper destination. In actual practice the equipment is quite different from that of a radio station — and its development was practically independent of radio — but in principal and for the purposes of easy explanation the operations are as just described.

On the open wire lines of the Bell System there are many stretches where a single pair of conductors is carrying simultaneously as many as 16 different conversations. In cables two pairs of wires often are arranged to carry 12 conversations at the same time. Although the special equipment that makes these arrangements possible is complicated and costly, it saves a great deal of wire line construction and thereby helps to make long distance service more economical. Since the war "carrier" has also been employed to derive additional telephone circuits on regular telephone lines in rural areas and on rural electric power lines over which telephone messages "hitch a ride" (as described on Page 21).

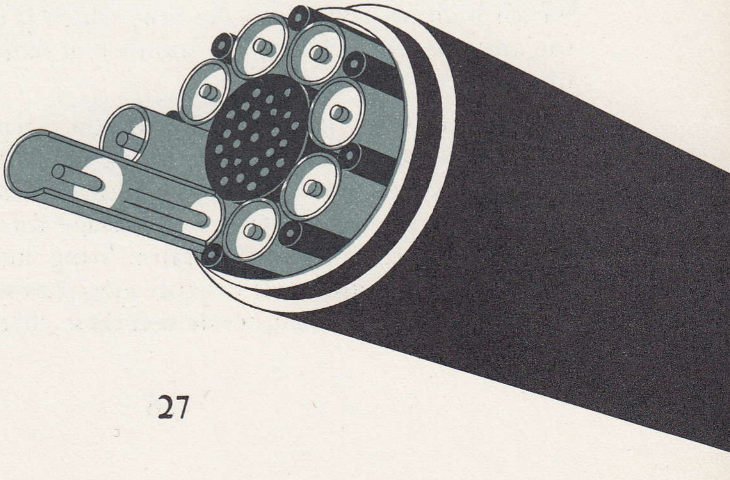
This same method of using currents of different frequencies to carry several telephone messages is also applied to telegraph messages, whether sent by key and received on a sounder or printed by teletypewriters. As many as 18 teletype messages can be sent at the same time over a single telephone circuit. Since this is so, sometimes a single line in the telephone plant will be carrying not only several telephone conversations, but as many or more teletype messages. Sometimes the line may also be carrying current from a picture-transmitting apparatus.

Coaxial Cable Systems

A further and extremely important advance in multi-channel, or "carrier," systems of even greater capacity was the development of coaxial cable.

A "coaxial" unit is a copper tube slightly larger in diameter than a pencil, with a single wire a little larger than a pencil lead held in its center by small discs of insulating material spaced about one inch apart along the wire. It forms a two-conductor transmission system like an ordinary circuit except that one conductor is cylindrical and encloses the other. Because of its size and shape, the copper tube is able to transmit a very wide band of frequencies.

Two such coaxial units with associated amplifiers make up the coaxial line. One coaxial unit transmits in one direction and the other transmits in the opposite direction. By means of the coaxial lines and terminal equipment we can transmit several hundred



Cross-section drawing of a coaxial cable containing eight units, showing how each tube holds a wire in its center.

telephone messages simultaneously, and can also provide television channels. Cables now being placed in the ground generally contain eight coaxial units. Along the line about every eight miles is a repeater station where the television or telephone currents are amplified.

Coaxial cable is now used in a nationwide network of four interconnected backbone routes: an Atlantic seaboard route from New York to Miami; a southern transcontinental route from Jacksonville to Los Angeles via Atlanta and Dallas; a mid-western route from Philadelphia to Chicago, via Pittsburgh and Cleveland; and a north-south route from Chicago to Jackson, Miss., via St. Louis.

A miniature coaxial cable model has been made, with a tiny repeater built right into the tube. This gives a glimpse of important progress ahead, for it is small enough to use in telephone lines in congested city areas where space for more cable is at a premium and where the load of conversations keeps constantly growing.

Radiotelephone Transmission

Telephone conversations usually are transmitted by wires at least over part of the distance, but not all telephone circuits are wire circuits. Radio links are common today in telephony, and are being used more widely all the time. Let's take a look at what happens at a radio broadcasting station.

In every radio transmitter, electrons are dancing all the time. Hundreds of thousands of times a second they rush up and down the antenna wires. Usually a vacuum tube is used to make them do so, but just how is another story. When the electrons from a speech highway come into the tube which is causing the dance in the antenna, they change the number of dancers or the tempo of their dance.

Wherever there is a receiving station electrons are set rushing back and forth in its antenna, keeping step with those in the transmitting antenna. In radio communication there are no highways with guiding wires to carry the message directly from sender to receiver. If the march in the transmitting antenna varies, then in all the receiving antennas the tiny electrons will also change their march. A radio-receiving set detects these changes. When the most electrons are busy rushing up and down your antenna, on the broadcast channel to which your set is tuned, there will be the most electrons moving through the coils of the loud speaker of your radio set. When there are fewer marching and countermarching in the antenna there will be fewer in the speaker. That is why the speaker diaphragm will be moved back and forth just as is the diaphragm of the distant microphone. And that, of course, is why the loud speaker in your radio reproduces the speech or music which is being transmitted from some distant source.

Radio transmission is very convenient when a large number of widely scattered receivers are to be reached simultaneously as in broadcasting. Radio transmission is more than convenient; it is necessary when the route over which communication is to take place is such that wires or cables can not be used to connect the transmitting and receiving stations. That is the case in communication to ships at sea, to airplanes in flight, or to motor vehicles en route; and likewise it is the case for most trans-oceanic telephone communication.

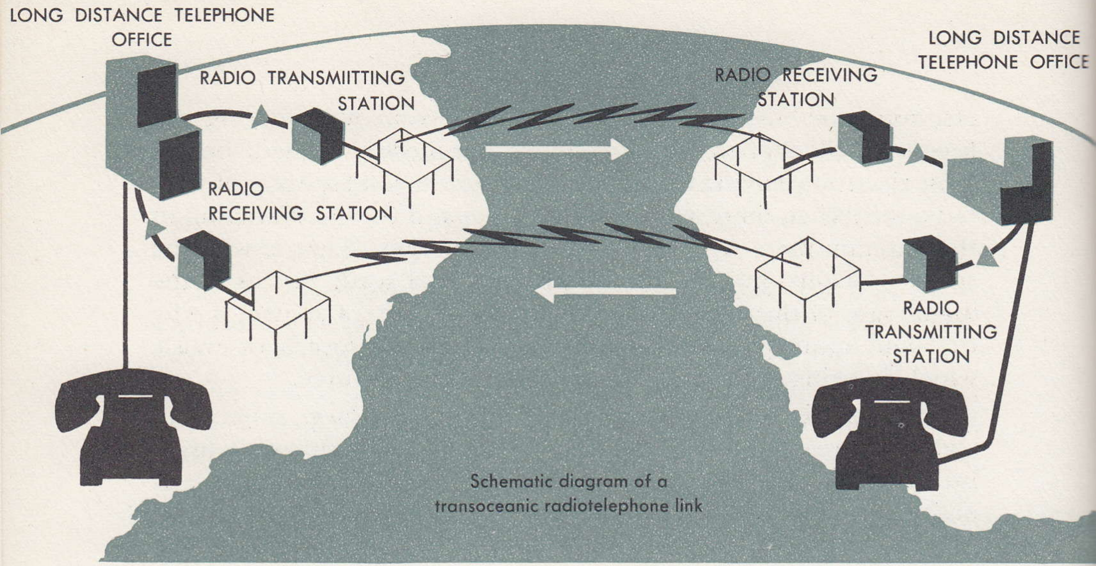
In radio broadcasting speech starts from the microphone in the studio of a broadcasting station. The current goes by telephone line to the radio transmitter, which sends it out to radio sets in thousands of homes. Even though a radio set is all contained in a single cabinet it really consists of two parts. One part handles the radiation which is received and obtains from it a current just like that which flowed from the microphone to the broadcasting transmitter. This current has to travel only a few inches to reach the second part of the set, which consists of the necessary vacuum tube amplifiers and the loudspeaker.

The telephone company does not use radio for broadcasting but does use it many times every day to interconnect people who want to talk with each other.

Overseas Service

Of course, whenever there is to be conversation by radiotelephone there must be, on each side of the gap across which radio transmission takes place, both a radio transmitting station and a radio receiving station.

The Bell Telephone System has several radio stations for overseas service. When one telephones from America to a point in



Schematic diagram of a transoceanic radiotelephone link

Europe or South America, his speech goes by wire, generally via New York City, to a transmitting station on the Atlantic coast; then by radio to the distant receiving station nearest to the place called, then on by wire to the called telephone. In the same manner, calls are routed through Oakland to trans-Pacific points and generally through Miami to Central American and Caribbean points.

Ship Telephone Service

In the same way, when a person makes a call from a telephone on land to a ship at sea, the current goes first from the telephone transmitter to the radio station. This station transmits by radio and on the ship is a radio receiving station which detects the telephone current.

That current, with the speech it carries, is then sent along a short telephone line to the particular cabin or room where the other party to the conversation has his telephone. The return speech is sent by radio transmitter on the ship to a receiving station on land, thence by land lines to the calling telephone.

The development of ship telephone service has paralleled that of overseas service. Shore station equipment for service to ocean liners is located in the same buildings as that for overseas service.

For years, the Bell companies also have furnished two-way radiotelephone service for coastal and harbor boats as well as for shipping on certain parts of the Great Lakes and some inland waterways.

Mobile Service

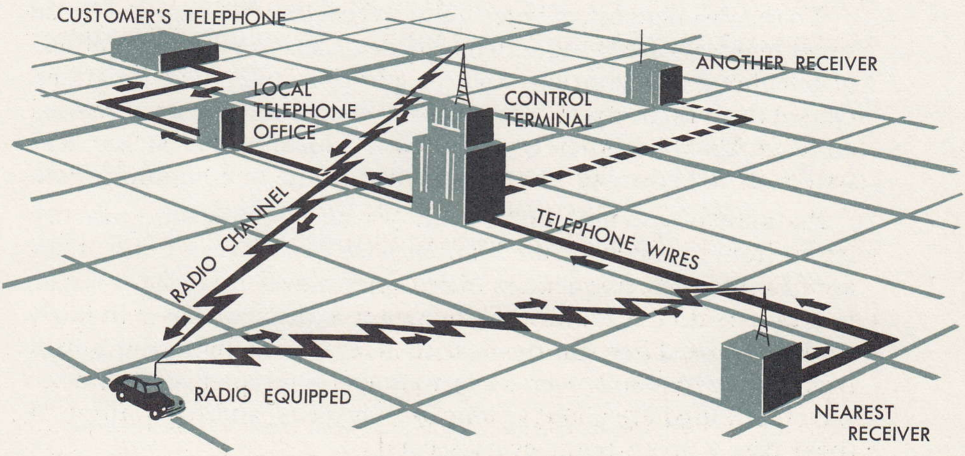
Bell System mobile telephone service now provides two-way voice communication for motor vehicles and other mobile units in most of the major cities and on many highways throughout the United States. At present there are more than 12,000 "traveling telephones" in service and they place and receive over 4,000,000 calls a year.

Mobile service is another means of furnishing telephone service to watercraft. Vessels in harbors and those plying inland waterways adjacent to highways where mobile service is available, may use the same or similar facilities as automobiles and trucks. Regular telephone service also is being provided on an increasing number of passenger trains.

A subscriber to the general two-way mobile service is able to talk from his truck or car to any one of the millions of telephones connected to the regular telephone network. Likewise, his vehicle can be called from any one of the millions of telephones.

The general mobile radiotelephone service operates like this:

Calls to and from vehicles are handled by mobile service operators. The conversations travel part way by telephone wire and part way by radio. For example, a man at his office desk who wants to talk to someone in a certain car or truck lifts his telephone



How mobile radiotelephone service operates in cities.

receiver and dials or asks for long distance. He then asks for the mobile service operator, to whom he gives the telephone number of the vehicle. Numbers such as WJ 6-6632, which do not conflict with any other numbers, are used.

The operator sends over the radio channel a signal which selects the particular mobile telephone desired and causes a bell to ring and a light to go on in the car or truck. When the driver sees or hears his signal he answers his telephone. His voice travels by radio to the nearest receiving station and thence by telephone wire back to the caller.

The person in the vehicle is able to make a call merely by lifting his telephone and pressing a "talk" button to signal the operator.

In large cities a number of receiving stations are located throughout the area so that the relatively low-powered radio transmitters in the vehicles are within range of a land receiver at all times. One of the receivers near the mobile unit picks up the voice signals and sends them on their way by telephone wire. Outside cities, transmitting and receiving stations are located along the highways being served.

Private mobile telephone systems also are leased and serviced by Bell companies to industrial concerns, utilities and police departments.

Radio Relay Systems

To the vast network of voice highways covering the nation, broad super highways are being added capable of carrying large "bundles" of telephone conversations and, in addition, television programs. One of these highways — coaxial cable — has already been discussed on Page 27. The other is radio-relay, which is also a "carrier" system. It is becoming increasingly important in communication.

Radio-relay systems employ radio waves, but they are quite different from the ones you are familiar with in your own radio. They are of super-high frequencies called microwaves. Like light waves, microwaves do not follow the earth's curvature, but travel in fairly straight lines. They can be focused like a searchlight and aimed from point to point over a clear, line-of-sight path. The microwaves now used are about as long as a cigarette, and four billion of them pass a given point every second.

Relay stations ranging up to 400 feet in height and spaced an average of about 30 miles apart, catch the radio beams, amplify them, and send them on to the next station. On top of the stations are special antennas, consisting of electromagnetic horns and lenses developed by the Bell System, which concentrate the microwaves sharply into beams. Because of this only a small amount of power is needed. Less than one watt—approximately the amount required to light a pocket flashlight bulb—is used in these systems.

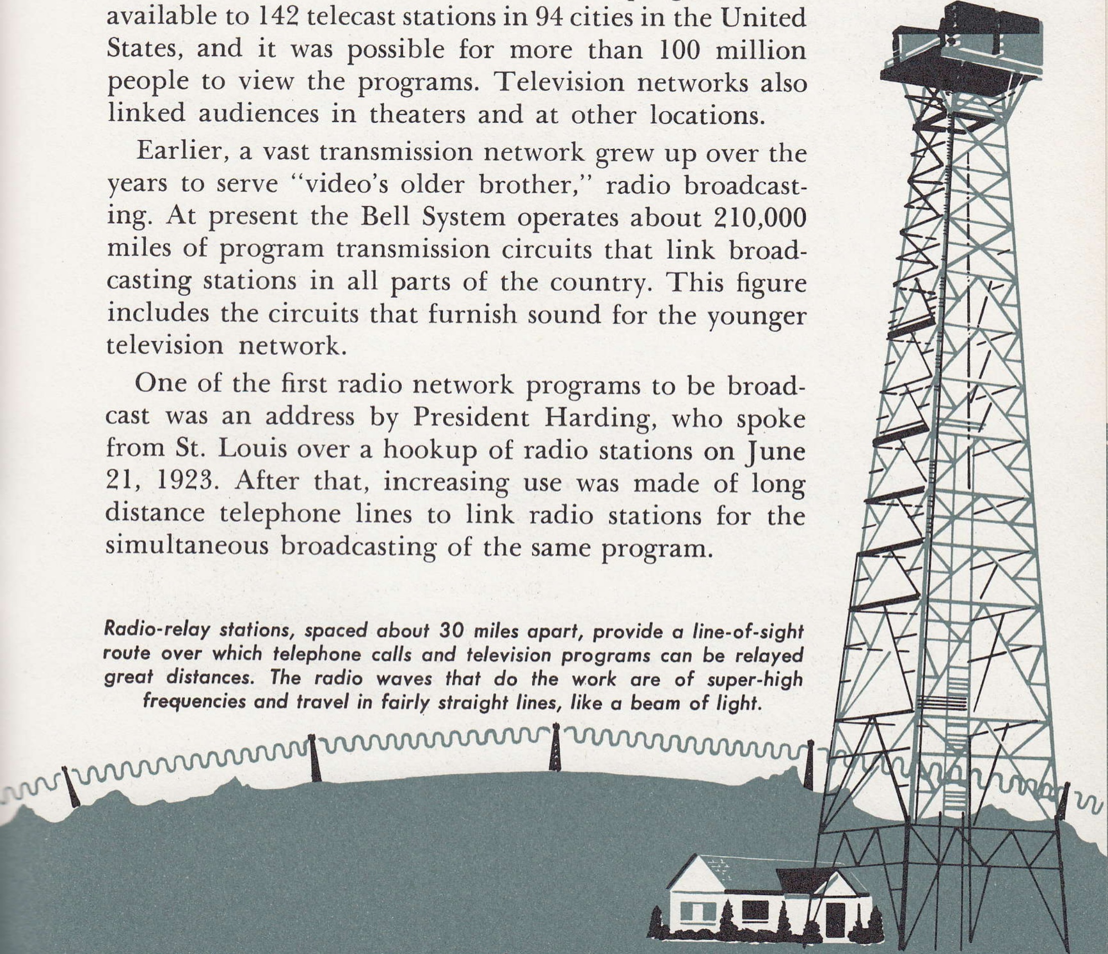
A radio-relay system that spans the continent, linking the east coast with the west, was opened in August, 1951. Other links stretch from the northern to the southern border of the country.

Special Networks

With the installation of coaxial cable and radio-relay systems on many long distance telephone routes, a network suitable also for the transmission of television is rapidly covering the nation. In midsummer, 1953, TV network programs were available to 142 telecast stations in 94 cities in the United States, and it was possible for more than 100 million people to view the programs. Television networks also linked audiences in theaters and at other locations.

Earlier, a vast transmission network grew up over the years to serve "video's older brother," radio broadcasting. At present the Bell System operates about 210,000 miles of program transmission circuits that link broadcasting stations in all parts of the country. This figure includes the circuits that furnish sound for the younger television network.

One of the first radio network programs to be broadcast was an address by President Harding, who spoke from St. Louis over a hookup of radio stations on June 21, 1923. After that, increasing use was made of long distance telephone lines to link radio stations for the simultaneous broadcasting of the same program.



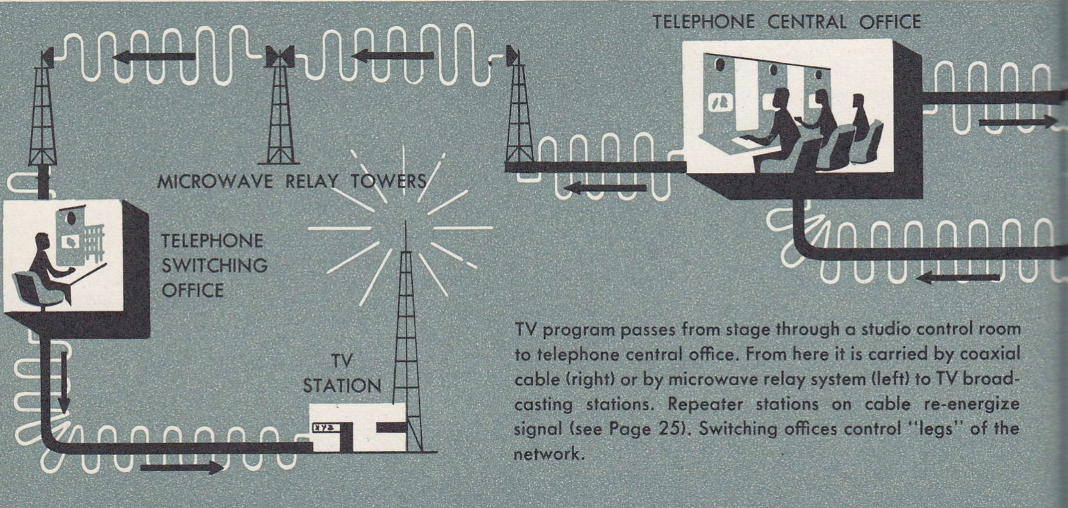
Radio-relay stations, spaced about 30 miles apart, provide a line-of-sight route over which telephone calls and television programs can be relayed great distances. The radio waves that do the work are of super-high frequencies and travel in fairly straight lines, like a beam of light.

To transmit the wide range of frequency in music, special pairs of wires were built into many of the older types of cables. These pairs are equipped about every half mile with special devices known as loading coils, developed primarily for use on program circuits. About every 50 miles special amplifiers are connected with the circuits. These loading coils and amplifiers keep the dance of the electrons, which transmit the music along the wires, from weakening too much. In the newer cables, programs are transmitted over multi-channel carrier systems, utilizing special terminal equipment.

In parts of the country where there are no cables, radio programs are transmitted over open wire circuits. No loading coils are necessary, but amplifiers are required about every 200 miles or less.

There are also many special teletypewriter networks to flash the written word from place to place for news services, police forces, government bureaus, and private industries. These networks are in addition to the regular teletypewriter exchange service (TWX) which permits the interconnection of teletypewriters through special telephone company switchboards. Special conference networks, sometimes on a nation-wide scale, frequently are arranged so that a number of persons in widely scattered locations may confer by telephone on questions of importance to them. Networks also are provided for the transmission of photographs by wire from a central point to a number of newspapers throughout the country.

Such special hook-ups have to meet very exacting requirements. Each section of a radio or television network must be so designed that it will work dependably and satisfactorily with many other sections. Switching points must be provided where branch channels can be brought into the network at will, preserving proper trans-



TV program passes from stage through a studio control room to telephone central office. From here it is carried by coaxial cable (right) or by microwave relay system (left) to TV broadcasting stations. Repeater stations on cable re-energize signal (see Page 25). Switching offices control "legs" of the network.

mission on each. Arrangements must be provided to permit very rapid changes in the network to care for successive programs. Standby equipment and alternate routes must be available to bypass affected areas should service be interrupted by an emergency. A large, carefully trained force of technical people must be on duty to maintain the complex equipment day and night and to insure a high quality of transmission from minute to minute.

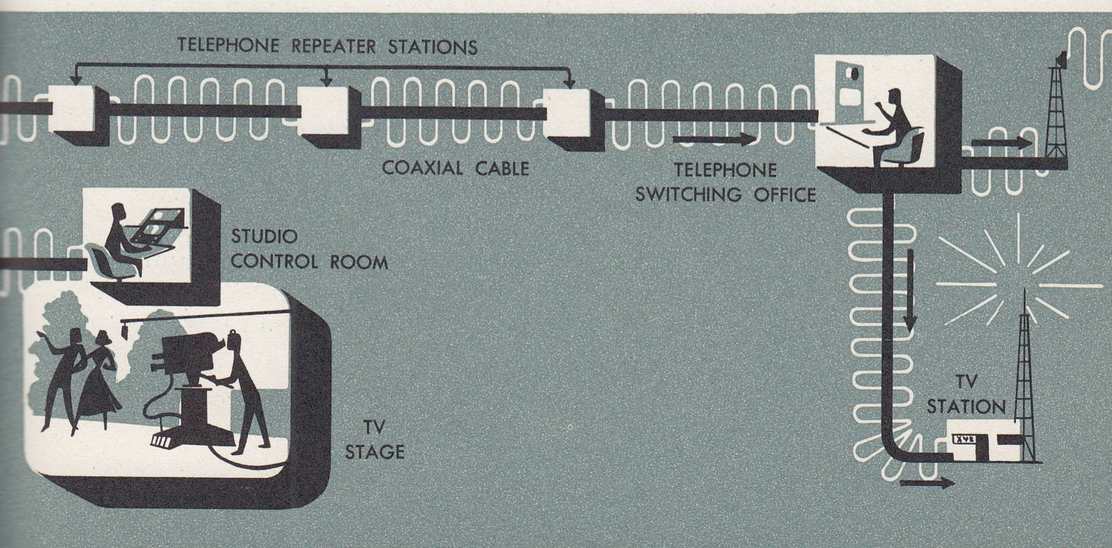
"Carrier" systems, described on previous pages, are the backbone of the Bell System's intercity networks. "Carrier" provides over 70 per cent of the intercity telephone circuit mileage, 85 per cent of the telegraph mileage, 40 per cent of the radio network mileage, and all of the intercity television program mileage.

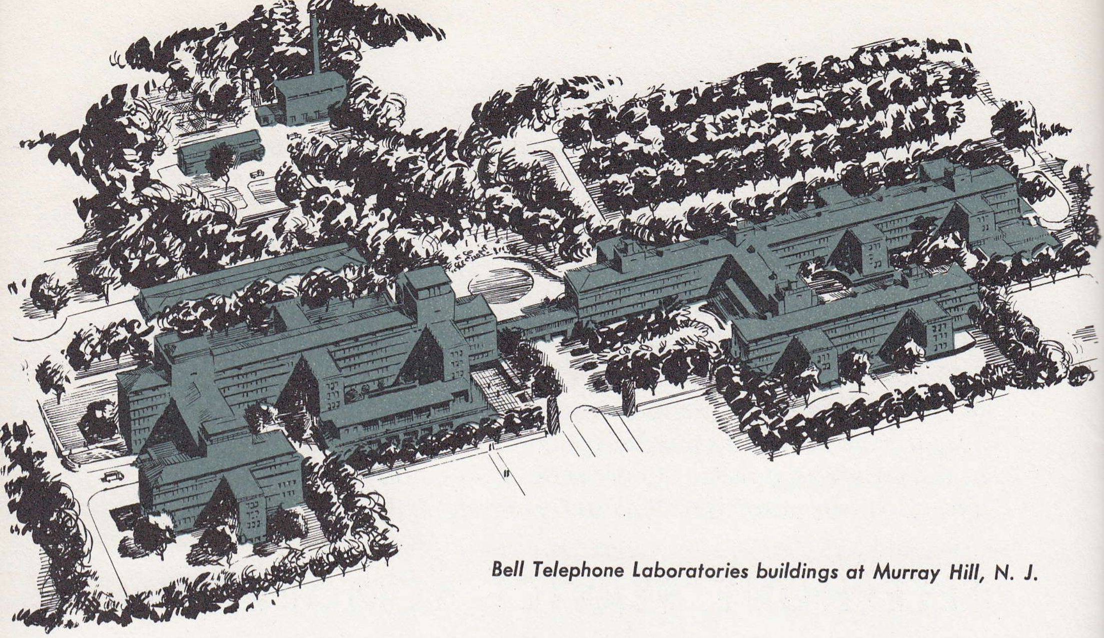
TELEPHONE SERVICE TOMORROW

Research and Development

A thorough knowledge of human speech and hearing, plus long effort to find a way to send several telegraph messages over the same wire at the same time, led Alexander Graham Bell to the conception of how speech could be transmitted over a wire. Step by inventive step, he reasoned his way to success little more than 75 years ago.

Ever since then, telephone research has been pursued continuously and vigorously by the organization now known as Bell Telephone Laboratories. There are experts in those Laboratories in every science that can contribute to the further advancement of the electrical arts of communication. Brilliant work by these scien-





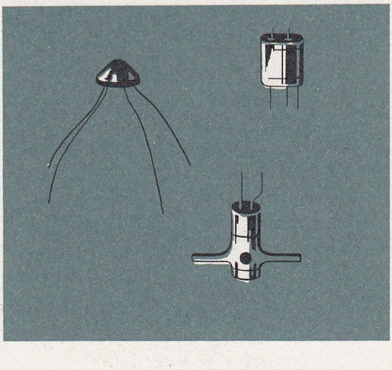
Bell Telephone Laboratories buildings at Murray Hill, N. J.

tists and engineers has constantly improved and extended telephone service.

For instance, a new and important electronic device called the *transistor* was invented recently at Bell Telephone Laboratories. Transistors can do many of the things that vacuum tubes do and more besides. They are very small, require only tiny amounts of power, but can amplify electric signals many thousands of times. Invention of the transistor may well prove to be one of the great landmarks of telephone research.

Another important new development from Bell Laboratories is a thin crystal of barium titanate, only about quarter of an inch square, that can store up electrical information and release it when ordered to do so — within one five-millionth of a second! In future, it is expected that one such crystal will do the work now done by a hundred electromagnetic relays or switches like those in dial telephone equipment.

Bell Laboratories people are aided in their search by engineers of the telephone companies who watch and measure the performance of the equipment in service. From their reports and suggestions as well as



Three of many types of transistors.

from fundamental research the Laboratories scientists explore and invent, develop and perfect to bring about economy and improvements so that telephone service in this country, always the best in the world, will be steadily better tomorrow than it is today.

Telephone Research Aids National Defense

Some very important weapons needed for our nation's defense depend largely on telephone research. This is because these weapon systems are, in many important respects, like telephone systems. A weapon system is what you have, for example, when you detect an invisible target by radar and then by electronic means automatically aim and fire guns to hit it. Similar systems control the dropping of bombs and the flight of guided missiles.

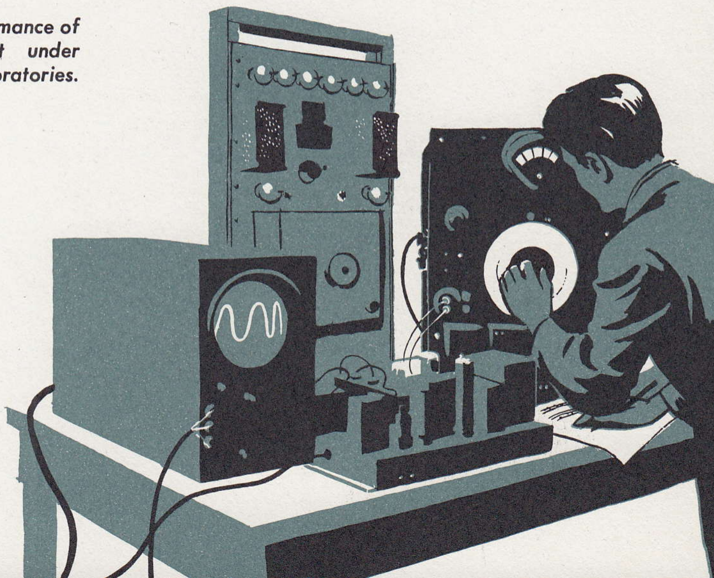
Today Bell Telephone Laboratories and Western Electric Company, the Bell manufacturing and supply organization, are devoting a good part of their effort to devising and producing such weapon systems for our armed forces.

The people of Bell Laboratories did not create systems of this kind purposely to aim weapons or guide the flight of missiles of war. Their purpose was to provide better telephone service. Nevertheless, the ability to defend ourselves against aggression has come to depend more and more on communications techniques.

Waves That Echo

The development of radar in World War II is a good example of the way telephone research has strengthened the country's fighting power. Radar stands for "*RA*dio *D*etection *A*nd *R*anging." Radar makes it possible to "see" in the dark, to seek out and

A scientist checks the performance of communications equipment under development at Bell Laboratories.



destroy enemy airplanes, ships, submarines and land targets.

Like your voice over the telephone, the radar signal is carried by electric waves. The men who learned to put these waves to work in the telephone system also learned how to put them to work for radar.

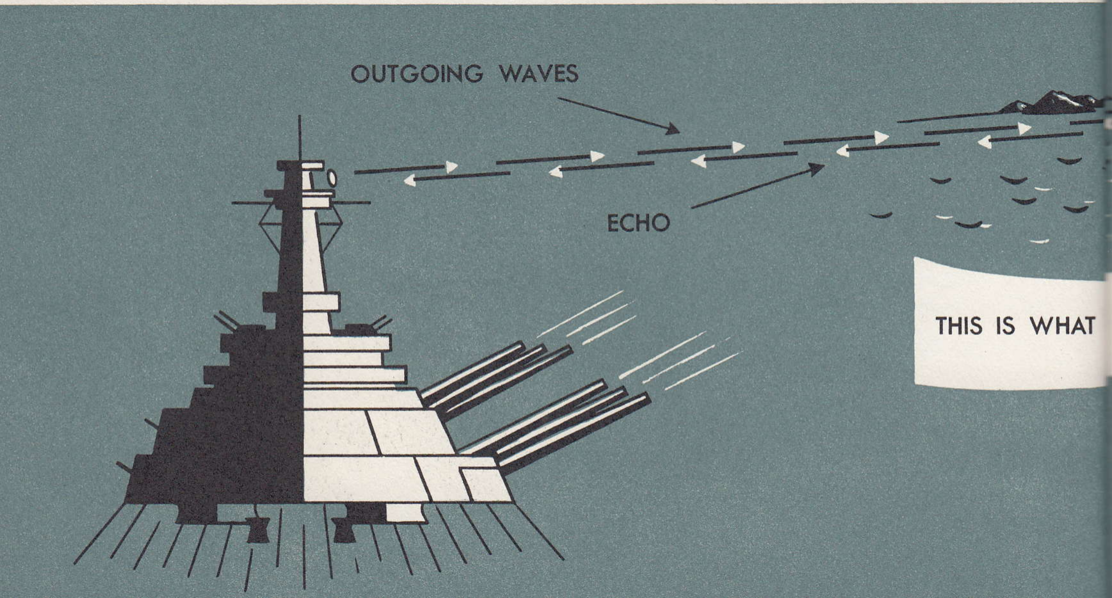
When you shout toward a cliff, sound waves echo back. Radio waves echo, too. Like a revolving searchlight, radar sprays the terrain or the sky with sharp bursts of radio energy, hundreds of them each second. As these echo, radar "listens" for each one. Then, electronically, the echoes emerge as a glowing pattern on a screen—similar to a television screen – revealing distant ships, planes, shores, factory areas.

The intensity of each radar flash is many times that of the brightest sunlight, while its echo is as faint as the light of the North Star on your outstretched hands.

Ancestry of Radar

Radars are made in many different shapes and sizes for different purposes but they all have basic elements in common. Years of Bell System experience with telephone, radio and television transmission have developed means for providing those basic elements.

There must be *electron tubes* to generate the outgoing electric waves and to amplify the energy that bounces from the target. For many years, telephone scientists have been developing tubes for communications purposes. Many of the tubes used in radar were invented or improved by them.



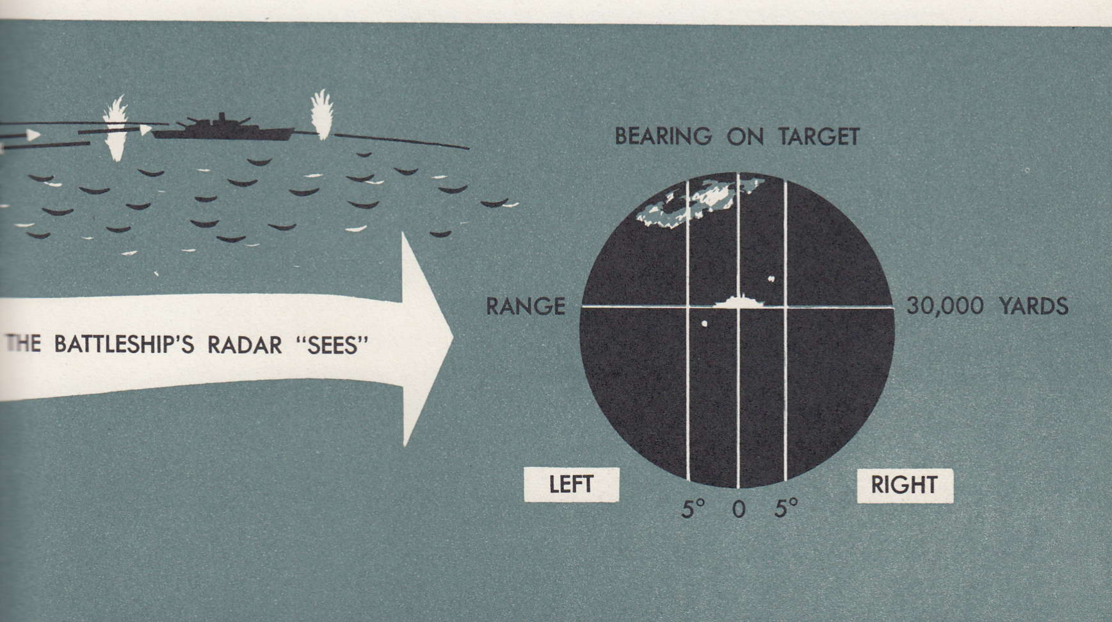
There must be special *conductors* to carry the elusive waves from one part of the radar to another. Telephone designers have devised the special wires, cables and wave guides needed to do this.

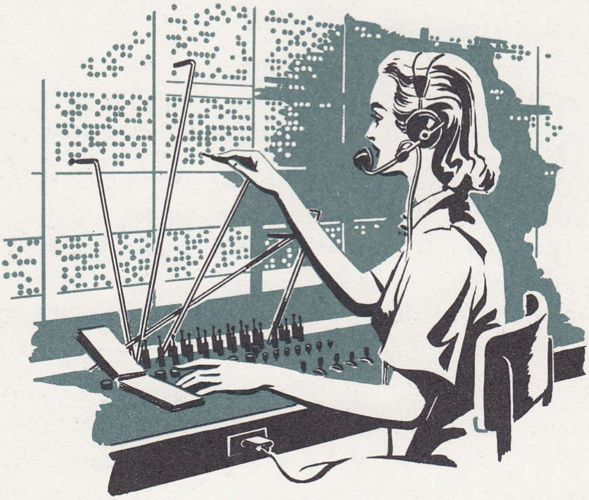
There must be *antennas* to pick up the impulses and direct the waves. Years of study of directional antennas by telephone scientists helped in the design of radar antennas.

There must be devices for *shaping the waves* and for *timing the pulses* and echoes. Bell scientists invented the wave filter which, like your radio dial, picks out a desired band of frequencies from all the others. And Bell experience in wave manipulation produced a method for timing radar that became the nation's standard.

There must be a *picture* of the echoes from the target. Bell engineers in 1922 made the first low-voltage cathode ray tube, in which a picture was projected on a fluorescent screen. In 1927, they staged the first public demonstration of long distance television by wire and radio.

This, in brief, is the story of how telephone research aided in the development of a great electronic weapon. Since the war, as Bell men of science have continued their work of improving the communications art, their efforts have led to new developments and techniques that are useful to national defense. Today, much of the Bell System's research and manufacturing potential is being devoted directly to vital projects that will bulwark the nation's military might.





At Your Service

The finest telephone system in the world is always at your service in America. The number of telephones is nearly 50,000,000, with four-fifths of them operated by Bell telephone companies and the other fifth by over 5,000 independently owned telephone companies and about 60,000 rural or farmer lines outside of the System but connecting with it.

Although resources national in extent are necessary to provide the amount and kind of service required in America, telephone service is basically home-town service. Nine out of ten telephone calls are local calls. The tenth may go across the country or across the ocean. This service is provided by your home-town friends and neighbors. The company which operates in your locality is, first of all, a good citizen of your community.

Telephone people in all branches of the business and in all parts of the country are striving constantly to find new ways of applying the magic of communication to provide more and better service than ever before.

A marvelous device indeed, the telephone!

TELEPHONE CHRONOLOGY

1847, Mar. 3 — Birth of Alexander Graham Bell, Edinburgh, Scotland.

1871, April 1 — Bell arrived in Boston to start his work in the teaching of the deaf.

1875, June 2—Bell's theory of the telephone confirmed by experiment.

1876, Mar. 7—The first telephone patent, No. 174,465 was issued to Alexander Graham Bell.

Mar.10—First complete sentence of speech transmitted by telephone in Boston.

June 25—Bell exhibited the telephone to the judges at the Centennial Exposition, Philadelphia.

Oct. 9—Bell conducted the first successful experimental two-way talk over the telephone between Boston and Cambridgeport, Mass., distance of 2 miles.

1878, Jan. 28—First commercial telephone exchange in the world opened at New Haven, Conn.

1884, Sept. 4 — Opening of telephone service, Boston-New York, 235 miles.

1885, Mar. 3 — Incorporation of American Telephone and Telegraph Company, New York City.

1892, Oct. 18 — Opening of telephone service, New York-Chicago, 950 miles.

1914, Feb. 26—Boston-Washington underground telephone cable placed in commercial service.

1915, Jan. 25 — Opening of First Transcontinental telephone line, New York to San Francisco, 3600 miles.

Oct. 21—First transmission of speech across the Atlantic by radiotelephone, Arlington, Va., to Paris.

1920, July 16—World's first radiotelephone service, between Los Angeles and Santa Catalina Island, opened to the public.

1921, April 11—Opening of deep sea cable, Key West to Havana, Cuba, 115 miles.

1923, June 7—Radio broadcasting networks began with a hook-up of four radio stations by long distance telephone lines.

Dec. 22—Opening of Second Transcontinental telephone line, southern route.

1925, Oct. 1 — Opening of long distance telephone cable, New York to Chicago.

1927, Jan. 7—Opening of transatlantic telephone service between New York and London, 3500 miles.

Jan. 17—Opening of Third Transcontinental telephone line, northern route.

April 7—First public demonstration of television by Bell System engineers.

1929, Dec. 8—Commercial ship-to-shore telephone service opened.

1930, April 3 — Opening of transoceanic telephone service to Argentina, Chile and Uruguay and subsequently to all other South American countries.

1935, April 25—First around-the-world telephone conversation by wire and radio.

1937, Dec. 8—Opening of Fourth Transcontinental telephone line.

1940, June 24—Television transmitted over coaxial cable from Convention Hall in Philadelphia to television studio in Radio City, New York.

1942, Dec. 21—Opening of first all-cable transcontinental telephone line with completion of buried cable, connecting existing cable systems of East and West.

1943, Aug. 22—New, improved equipment for the dialing of called telephone numbers in distant cities directly by operators, placed in service in Philadelphia.

1946, Feb. 12—New York-Washington coaxial cable circuits opened for television transmission on an experimental basis.

June 17—Opening of experimental mobile radiotelephone service in St. Louis.

1947, Aug. 15—Opening of commercial telephone service for passengers on certain trains running between New York and Washington, D. C.

Nov. 13 — Opening of New York-Boston radio relay system for experimental service.

1948, June 30 — First public demonstration of the transistor by Bell Telephone Laboratories.

1949, Oct. 17—Dialing of transcontinental telephone calls by operators started with the joining of toll dialing networks on East and West coasts.

1951, Sept. 4 — Coast-to-coast television began over transcontinental radio relay system.

Nov. 10—Long distance dialing by telephone users began on trial basis at Englewood, N. J.

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