SPANNING THE CONTINENT BY RADIO RELAY

A New Medium of Transmission Is Taking Its Place Beside Open Wire, Cable, and Coaxial Systems as a Conveyor of The World's Telephone Messages

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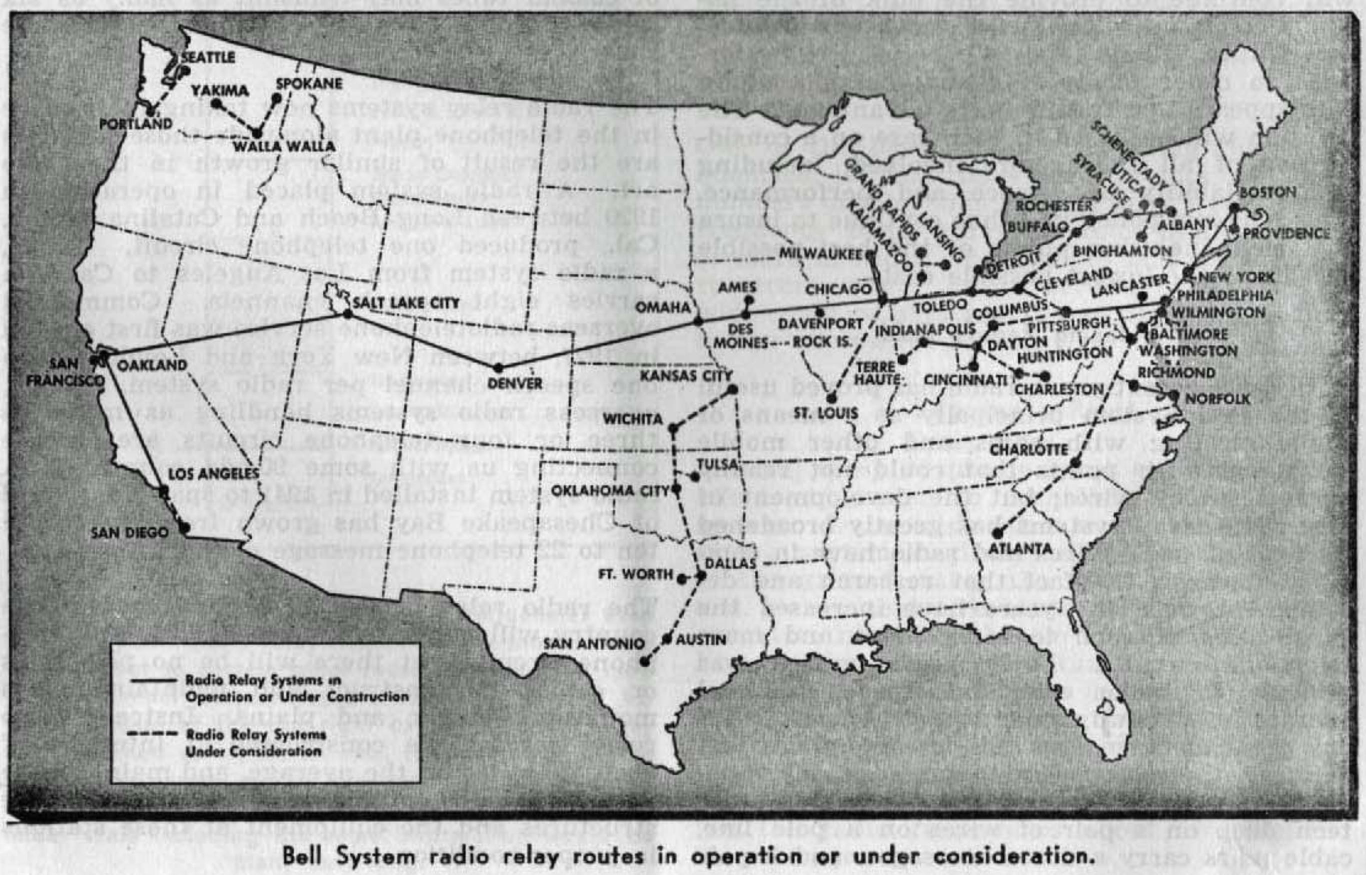
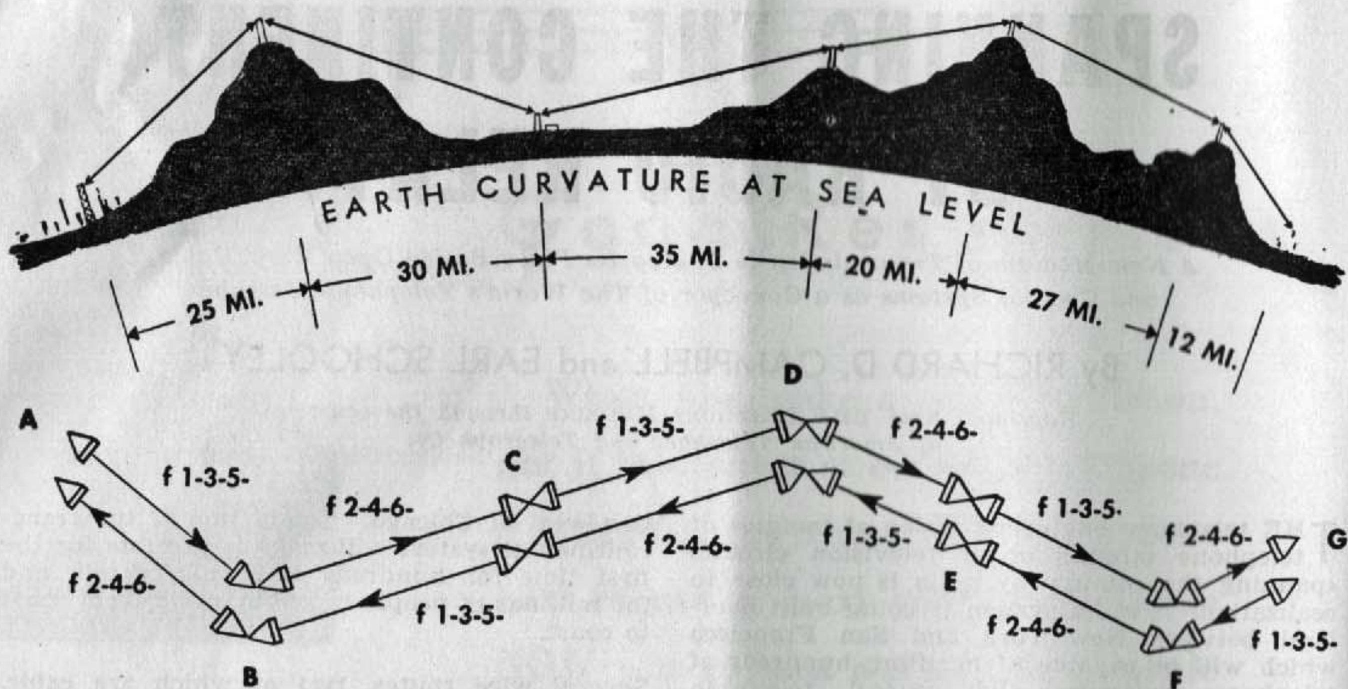
THE telephone engineer's vision of bundles of telephone circuits or of television circuits spanning the country by radio is now close to realization. A radio system is being built overland between New York and San Francisco which will be capable of handling hundreds of telephone messages and several television programs. Already it is being used from the East Coast to Omaha—1,300 miles—and in 1951 the new system will push westward another 1,700 miles from Omaha to link the East Coast and the West. Over one hundred telephone circuits—only a small part of its ultimate capacity—are planned for operation initially in the section west of Chicago. Completion of the transcontinental system will make it possible for the first time for hundreds of people to talk and for millions of people to see by radio from coast to coast.

Several wire routes, two of which are cable, already connect the East and West Coasts. But additional facilities are needed, and radio relay is being used for this new transcontinental system because it affords an economical means of providing them. This does not mean that radio relay will replace existing means of wire communication. On the contrary, wire facilities



Bell System radio relay routes in operation or under consideration.



The upper diagram represents a section of radio relay route, showing stations located to permit line-of-sight transmission. The lines between towers indicate direct radio paths, the span length being determined by considerations of attenuation, noise, and fading. Below is a corresponding map of the route, showing the two directions of transmission on separate beams. The route is zigzagged to avoid possible interference between sections using the same frequencies.

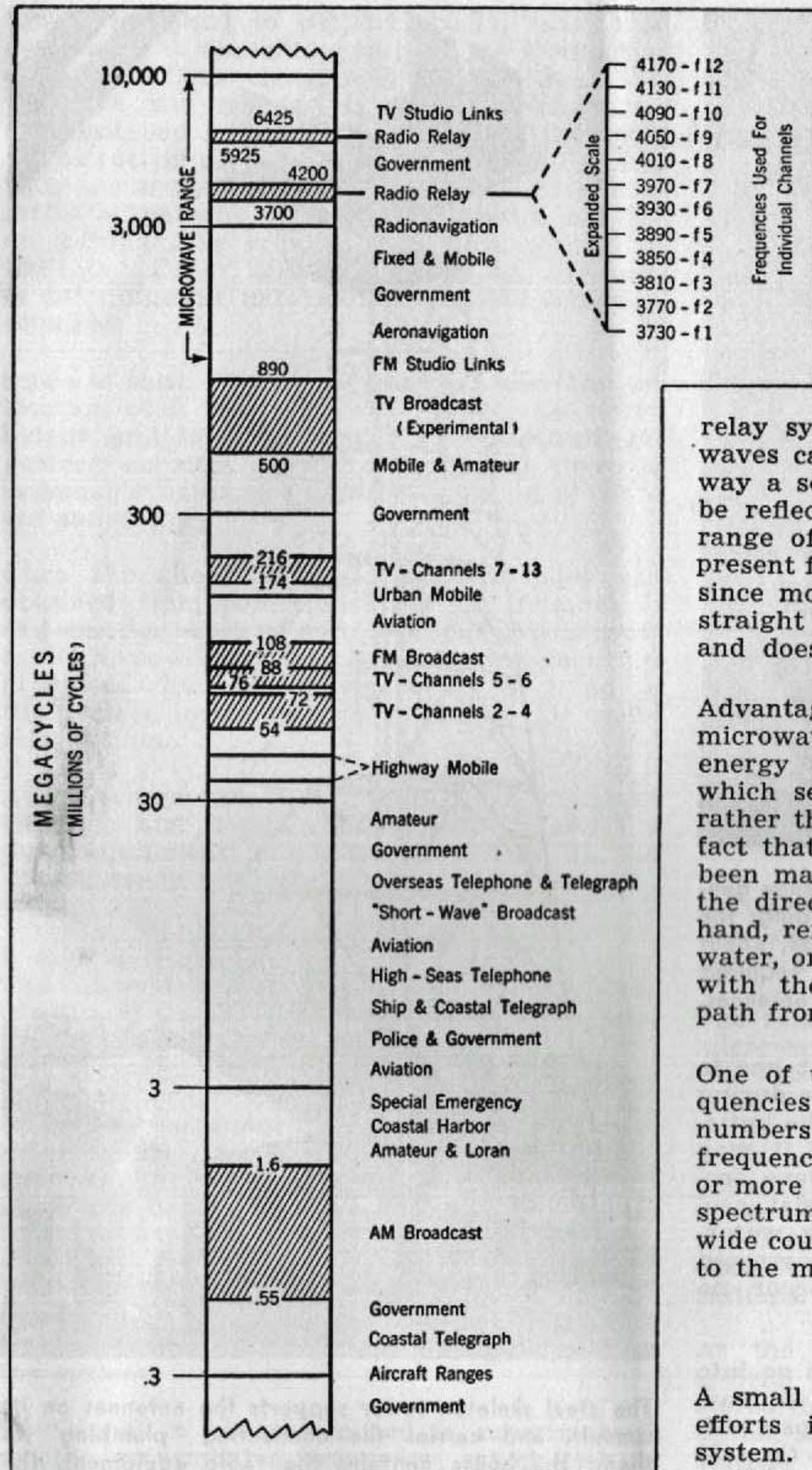
will continue to provide the bulk of the nation's communication facilities for the foreseeable future. Radio relay will be used in preference to other forms of communication where this appears to afford definite advantages. The decision will be based in each case on a consideration of all the factors involved, including cost, reliability of service and performance. This long-run policy will thus continue to insure the telephone-using public of the best possible service at the lowest possible cost.

Widening Radio's Field

Until quite recent years, radio has proved useful in the Bell System principally as a means of communicating with ships and other mobile units and with points that could not readily be reached by wires; but the development of new radio relay systems has greatly broadened its field of use. Wires and radio have in common, however, the fact that research and development over the years have increased the capabilities of each to carry more and more telephone circuits. Forty years ago, it was difficult to make even one speech channel operate successfully over a pair of wires for any great distance, and radiotelephony was just entering the experimental stage. Today, telephone conversations are being "stacked up" sixteen deep on a pair of wires on a pole line, cable pairs carry a dozen messages, and a pair of coaxial tubes may transmit as many as six hundred long distance conversations at one time.

The radio relay systems now taking their place in the telephone plant alongside those facilities are the result of similar growth in the radio art. A radio system placed in operation in 1920 between Long Beach and Catalina Island, Cal., produced one telephone circuit. Today, a radio system from Los Angeles to Catalina carries eight speech channels. Commercial overseas radiotelephone service was first opened in 1927, between New York and London, with one speech channel per radio system. Today, overseas radio systems handling as many as three or four telephone circuits are in use connecting us with some 90-odd countries. A radio system installed in 1941 to span the mouth of Chesapeake Bay has grown from the initial ten to 22 telephone message channels.

The radio relay system being built across the country will be able to carry hundreds of telephone circuits, yet there will be no pole lines or cables to construct and maintain across mountains, rivers, and plains. Instead, radio relay stations are constructed at intervals of about 30 miles on the average, and maintenance will be needed, therefore, only to keep the structures and the equipment at these stations in proper condition.



The location in the spectrum of the frequencies used for Bell System radio relay transmission is shown above with respect to certain other radio services. The individual channel frequencies are indicated on the expanded scale at the top right of the diagram. They are identified as f1, f2, f3, etc., to correspond to the frequencies shown on the diagram opposite. Use of a logarithmic scale is essential here, since a legible linear scale including the same information would be many feet long.

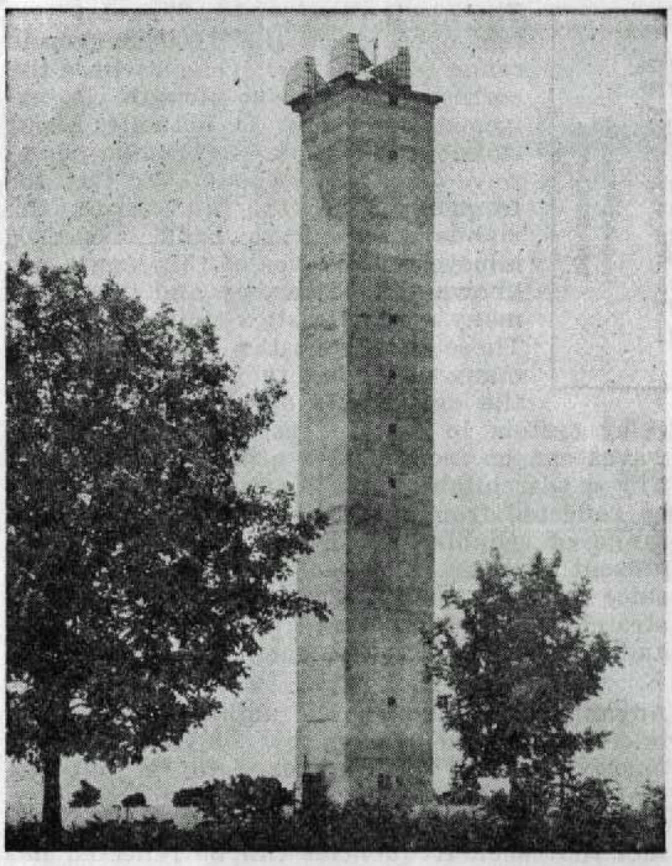
The newly developed radio relay system operates in the 4,000 megacycle range (4,000,000,000 cycles), where the corresponding wave length is extremely short. It is, actually, about three inches long, as compared to wave lengths of about 1,000 feet for frequencies in the middle of the standard broadcast band (550-1,600 kilocycles). Waves of this length are known as microwaves, and they have many characteristics similar to light. These characteristics prove useful in many ways, but they also complicate the design and operation of a radio relay system in certain respects. The microwaves can be focused into a beam in the same way a searchlight sends a beam, and they can be reflected from relatively flat surfaces. The range of reliable microwave transmission with present facilities is limited to line-of-sight paths, since most of the energy travels in essentially straight lines from the transmitting antenna and does not follow the earth's curvature.

Advantage is taken of the ability to focus the microwaves into a beam by concentrating the energy from a transmitter into an antenna which sends it to a particular radio receiver, rather than scattering it in all directions. The fact that such frequencies can be reflected has been made use of in some instances to change the direction of the radio beam. On the other hand, reflections from salt flats, large bodies of water, or treeless plains may seriously interfere with the radio signals traversing the direct path from transmitter to receiver.

One of the basic reasons for using these frequencies is that television circuits or large numbers of telephone circuits need a very broad frequency band—three or four million cycles or more in width. In order to find space in the spectrum where bands several million cycles wide could be obtained, it was necessary to turn to the microwave frequencies.

Selecting a Route

A small army of people must coordinate their efforts in order to establish a radio relay system. Once a decision is reached to build such a system, engineers study the topography of the ground, using the best maps available, and pick a tentative route. Since the earth's curvature must be taken into account in finding line-of-sight paths, it is natural to seek elevated sites for repeater stations in order to extend the distance between them and thus minimize the number of stations required. Hilltops are likely to make good repeater station locations. Elevations are desirable that will permit sending the radio frequencies about 30 miles on the average.

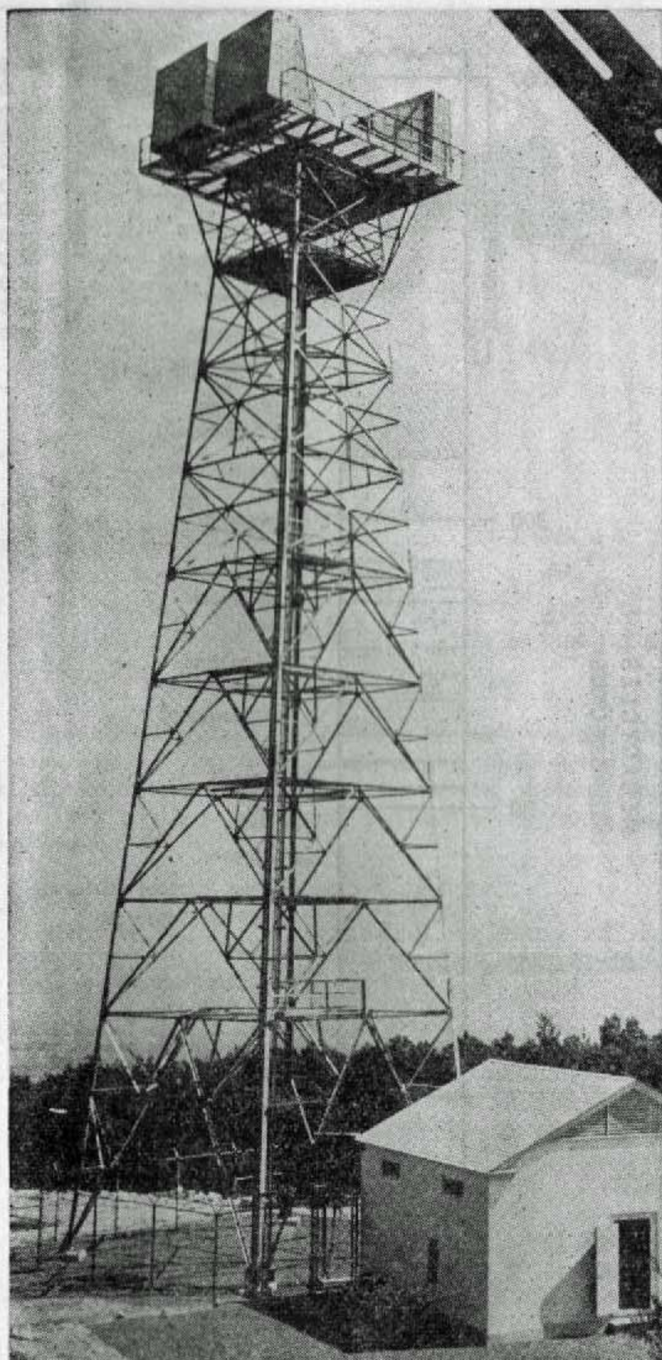


The antennas are on the top and the emergency generator is in the bottom of this concrete building; the radio equipment and power supply are inside, about half-way up. The airplane warning beacon required on most such towers is visible between the antennas.

Remembering that the radio equipment has to be cared for, a site which is inaccessible during the winter months will probably not be satisfactory, despite any other advantages it may have. Remembering, too, that microwave frequencies can be reflected, relatively flat sections of the earth's surface—including water-covered areas—must be avoided or else crossed in such a way that, if reflections do occur, no serious harm will be done.

When the map work is complete, crews go into the field to study the locations selected from the maps. In some areas, the only maps available are based on surveys made more than 60 years ago. In several cases, hills appearing on these maps were found, on field check, to be incorrectly located. Locations picked from maps were often found to be already occupied by farm buildings or, in some instances, by radio stations.

Sometimes hilltops with good access, power supply, and other advantages cannot be used because higher hills, trees, or city buildings are in the line-of-sight path, or because of restrictions imposed by local or federal laws.



The steel skeleton tower supports the antennas on its summit, and carries the connecting "plumbing" to them; the house contains the radio equipment, the power supply, and the emergency generator.

Even though hilltops are used, towers are required in some locations to provide an additional 200 feet or so of height which may be necessary for reasonably long line-of-sight paths to the next relay points.

Tentative sites for the antenna towers are picked and temporary towers are erected. These

towers are used to support special radio test equipment to check the path to the next adjacent site. This check may indicate that the tentative site selected is not satisfactory because of bad reflections, or because the path is obstructed by a hill or by a large structure, such as a water tank. The tests may also indicate that shorter or taller towers are required than the preliminary review seemed to indicate. Other tests are made on the soil, to determine the nature of the tower foundation required.

Since a shift of even a few hundred feet in location of a relay site may affect the tower height and location of the two adjacent repeaters, no sites are purchased until there is reasonable assurance that all sites on a route are satisfactory.

Once the sites have been secured, bids are obtained from contractors for the foundation and erection work at each location. Roads must be built, power brought in, and other facilities provided which are not generally at hand in the remote locations usually chosen for radio relay points.

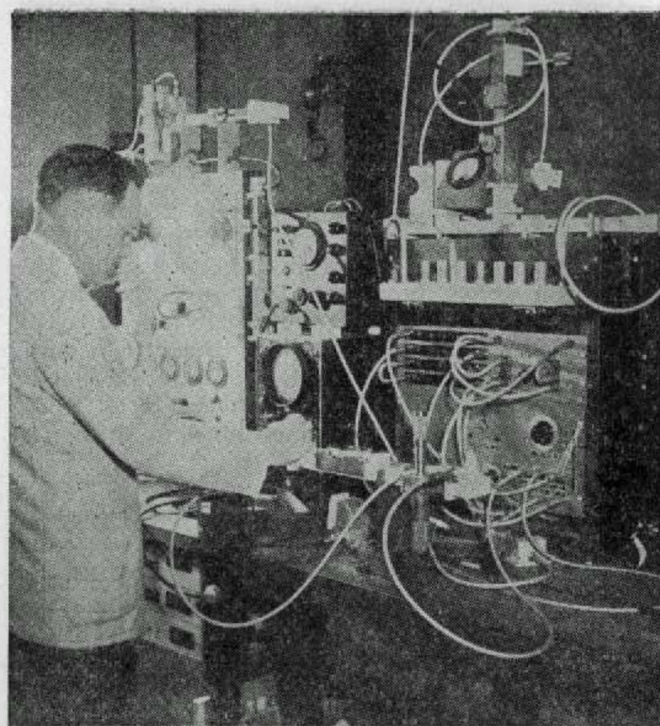
About ten months later, if all goes well, the buildings and towers will be complete and the radio equipment and antennas will be on the ground ready for installation.

Using Microwave Frequencies

The equipment used in the radio relay system consists of the same basic elements as are used for other Bell System radio services. These include radio transmitters, radio receivers, and antennas. The main differences between the radio relay equipment and that used for the other systems are the use of microwave frequencies, the new techniques involved in the apparatus design, and the ability of the equipment to handle wide frequency bands.

The functions of the radio equipment can be readily understood by following a simplified account of the course of a signal passing over the system.

The signal to be transmitted is superimposed on the transmitting frequency, which lies in the range from 3,700 to 4,200 megacycles. This radio signal is amplified and then sent to an antenna, where the energy is concentrated in a narrow beam directed through space toward the first repeater station along the route. Since the energy is concentrated, it is not necessary to use the millions of watts which would be required if the energy were scattered in all directions, as in radio broadcasting. Instead, the actual radio power output is only half a watt, or about the same amount of energy required to operate a flashlight bulb. Yet to



A Bell Telephone Laboratories engineer conducts experimental work on a transmitter-modulator unit of radio relay equipment, shown at the upper right.

obtain the power to provide adequate amplification and this amount of radio energy, several hundred watts of input power is required.

The relay station receives the relatively weak microwave signal, amplifies it to make up for the loss it has suffered in spanning the distance from the preceding station, and sends it on to the next station. This process is repeated over and over again at successive repeater stations located at intervals along the desired routes. A signal transmitted over the entire system between New York and San Francisco will, incidentally, pass through 105 relay stations.

At the distant terminal of the radio relay system, the signal, after amplification, is restored to its original form. If it is a television signal, it is ready for delivery to the broadcast station. If the signal consists of a group of telephone circuits, it must be connected to equipment similar to that used in coaxial and other carrier systems, which performs the feat of unscrambling each telephone conversation from the others before delivery over individual circuits to the customers' telephones.

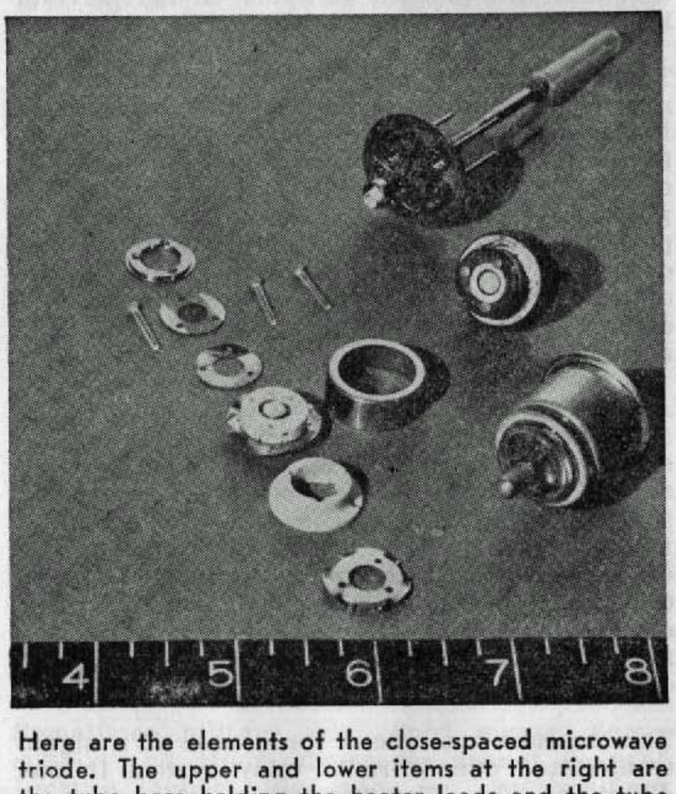
This account has traced the course of a signal transmitted over a radio relay system in one direction only. For two-way service, such as is necessary with telephone communication, equipment must also be provided for transmission in the reverse direction. The traffic on many routes may require the installation of additional radio equipment for the broad-band channels which would be necessary to handle more bundles of telephone circuits or additional television programs.

A single radio relay antenna may transmit as many as six broad-band channels in one direction. Another single antenna may receive the same number. Hence, only four antennas in all—one transmitting and one receiving antenna side by side facing in one direction and a similar pair facing in the opposite direction—will suffice at each radio relay point along a route equipped to handle six broad-band channels in the two directions.

If a branch route takes off from a relay station in a different direction an antenna is also needed for transmitting toward and another for receiving from the new direction.

Microwave Transmission

Every advance in telephone science and telephone service represents foresight, long-range planning, guided and coordinated attack upon a problem, and a practical solution. In this pattern, radio relay is the outcome of long and fruitful effort by the Bell Telephone Laboratories, and its installation bespeaks the utmost skill and manufacturing precision by the Western Electric—the Bell System's division of manufacture and supply.



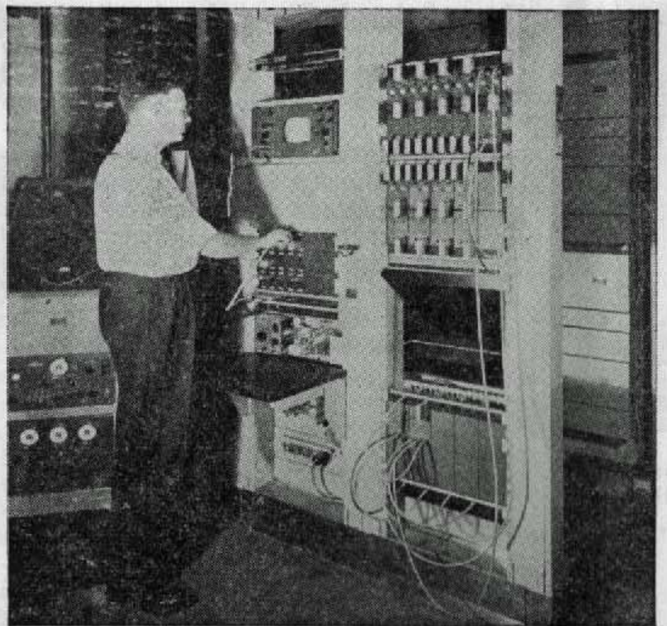
Here are the elements of the close-spaced microwave triode. The upper and lower items at the right are the tube base holding the heater leads and the tube envelope; the rest are components. The inch scale indicates the small size of the tube.

A better appreciation of the development and manufacturing effort required in producing the radio relay equipment can perhaps be obtained by considering a few of the components involved. Take, for example, the close-spaced microwave triode (Western Electric Type 416A microwave vacuum tube), which is the very heart of the equipment. It is used to generate and amplify the extremely high frequencies employed for transmission. This tube, which is about the size of an English walnut, is the same in principle as any ordinary three-element vacuum tube having a cathode, grid, and plate. The placing of these elements in the extremely small space required to make the tube work at these frequencies is a triumph of design and manufacture. The grid structure employs wire only about one-tenth the thickness of a human hair, and the distance between the grid and the cathode is one-fifth the diameter of a hair. Certain critical parts are gold-plated to resist corrosion. Six such tubes are required for each one-way channel at each relay station.

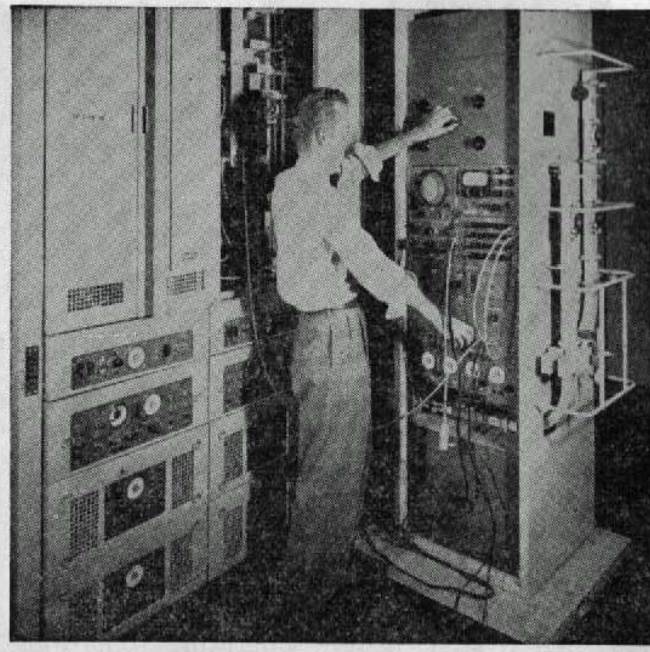
At microwave frequencies, the energy is easily radiated, and therefore ordinary wire connections cannot be used for guiding these frequencies from one place to another. It has consequently been necessary to guide the energy by means of pipes or tubes, called waveguides, and frequently referred to as "plumbing." Sections of waveguide are made in various lengths and shapes, including elbows and other bends, twists, and straight sections. A cross-section is about half the size of a playing card. The various sections are bolted together by means of flanges. Dents and other deformations of the waveguide and flanges must be guarded against because, even when relatively minute, they are likely to result in transmission irregularities.

Microwave transmission would not be practicable without highly directive antennas, and these too deserve particular consideration. The type normally used in the radio relay system is made of metal, and acts in the same manner for microwave frequencies as a glass lens does for light waves. For this reason, it is commonly referred to as a lens antenna. By the use of such an antenna, the microwave frequencies can be focused into an extremely sharp beam. Lens antennas are used for both transmission and reception. If non-directional antennas were used, the output of the transmitter would have to be increased to about 50,000,000 watts of power, instead of the one-half watt used with the lens antennas, in order to produce the same transmission effectiveness.

Equipment has been developed for use at the



This man is watching a video monitor in a patching bay at a radio relay station where a branch connection is provided to a television broadcasting station. A test console may be seen at the left.



The three large cabinets at the left—one with its door open for testing—are radio transmitter-receiver bays. The equipment in each serves as a relay station to receive, amplify, and transmit one-broad-band channel in one direction. The test bay with which the man is working is used to locate trouble and to make routine checks of the equipment.

repeater stations and at special maintenance centers to assist in determining the overall performance of the radio equipment during routine testing or to locate the source of troubles which might develop.

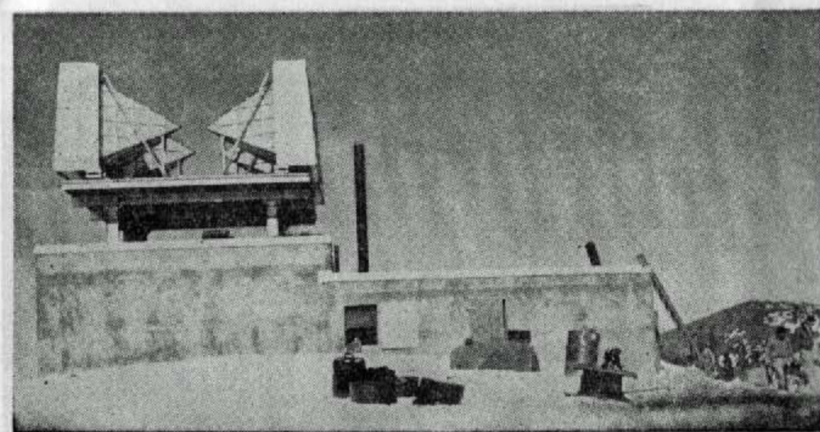
The reliability of service over the radio relay system can never be better than the reliability of the power supply from which it operates. For this reason, the equipment is operated from storage batteries. Commercial power is used as the primary source of energy at most stations. However, to insure continuity of service, a standby gasoline or diesel engine generator, capable of automatically taking over the load in case of a failure of commercial power, is installed at each station.

Rectifiers which provide the required current supply for the batteries are installed in duplicate, and if one fails, the other takes over automatically. The storage batteries are capable of carrying the load for six to eight hours, which is generally time enough for a maintenance man to get to a station if something should go wrong; and in some locations difficult of access, a larger battery is used which is capable of carrying the load for as long as 24 hours, further insuring continuity of service.

Since the repeater stations are designed for unattended automatic operation, a control system is used to provide information at special maintenance or alarm centers concerning the operating condition of the individual stations.

The system produces a visual and an audible signal at the alarm center when trouble develops at an unattended station. Upon receipt of such an alarm, 42 different alarm conditions at the unattended station can be checked from the alarm center. These conditions range from an open door at the station to failure of a rectifier or the failure of an aircraft tower warning light. The alarm center is thus apprised promptly of unsatisfactory conditions at the unattended stations, and remedial action can be taken.

In a long radio relay system, the maintenance work must be carried on from regional maintenance centers located at strategic places having access to the individual stations along a section of route usually ranging from 100 to 300 miles in length. A special telephone circuit is provided to interconnect the individual stations in each of these sections with their associated alarm and maintenance centers. To facilitate coordination of the maintenance work in the individual sections another circuit is provided which interconnects only the terminals, the main stations, the alarm centers, and the maintenance centers of an entire system—such as the one between New York and Chicago. These circuits are usually provided by wire, but separate radio facilities have been used in a number of cases to connect relay stations at remote points.



This radio relay station, under construction on Mt. Rose, Nev., is nearly two miles above sea level, the highest elevation of any station in the entire transcontinental system.

Problems and Capabilities

The Bell System is now operating some 8,150 channel miles of broad-band radio relay systems. Seventy percent of this mileage is provided by the use of the newly designed microwave equipment, and most of this was placed in regular service in September of 1950. All of the radio relay facilities at present in service are being used commercially for television transmission. The experience to date with the newly developed equipment confirms the expectation that this system can transmit present-day television signals over very long distances with excellent results. Test pictures transmitted twice around the New York-Chicago system, a distance of approximately 3,300 miles, can easily be mistaken for pictures which have been transmitted only over local pick-up facilities.

As may be expected with any new development, some equipment difficulties were experienced during early tests of the microwave radio relay systems. Unexpected sources of noise and transmission irregularities had to be tracked down and minimized or eliminated. Equipment troubles were studied and the necessary corrective action was taken. Plenty of cooperative effort made it possible to place the system in regular operation on schedule.

On the operating side, men had to be trained in large numbers to assume the maintenance and operating duties involved in the use of this new form of communication system. Here, too, the successful operation of the systems now in use speaks well for the manner in which this program was carried out, and for the hard work, loyalty, and skill of the plant personnel.

Tests made on the New York-Chicago system give further support to laboratory tests proving the practicability of carrying large groups of telephone circuits over transcontinental distances. Needed telephone circuit facilities are to be provided by the use of radio relay systems on a number of routes during 1951—including service over the Chicago-San Francisco route. Present plans contemplate that by the end of 1951 the total channel miles of broad-band radio relay systems in operation will have increased to nearly 25,000. Of these, about one-third will be equipped to provide a total of about 800,000 circuit miles of telephone circuits.

There are still things to learn about radio relay, and of its future no man can speak with certainty. But already radio relay has shown that it will have a vital part to play in meeting the communication needs of our nation, in peace or in war. The thousands of miles of radio relay now in service and being constructed will take their place alongside open wire, cable, and coaxial systems as a conveyor of the world's messages.

National Radio-TV News, August-September 1951

Courtesy of Bob Dobush