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Telephone

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An objective account of the invention of the telephone itself is given, and the subsequent development and growth of telephony are described. A statistical summary is presented of the intensity of development in different parts of the world. This is followed by a comprehensive review of technical developments, including progress in station instrumentalities, and transmission and switching principles and methods. The article concludes with a prediction of trends to be anticipated in telephony as a result of recent technical advances.

The term "telephone" (from the Greek roots τῆλε, far, and φωνή, sound) was formerly used to describe any apparatus for conveying sounds to a distant point. Specifically, the word was applied as early as 1796 to a megaphone, and not long afterward to a speaking tube. Subsequently the name "string telephone" was given to the device invented long before by Robert Hooke (1667), in which vibrations in a diaphragm caused by voice or sound waves are transmitted mechanically along a string or wire to a similar diaphragm which reproduces the sound. Still later, devices employing electric currents to reproduce at a distance the mere pitch of musical sounds were called telephones. Nowadays, however, this name is assigned almost exclusively to apparatus for reproducing articulate speech and other sounds at a distance through the medium of electric waves. The term "telephony" covers the entire art and practice of electrical speech transmission, including the many systems, accessories and operating methods used for this purpose.

INVENTION

Like most inventions, the telephone drew heavily upon previous work and had scarcely appeared before notable improvements were made. Among the pioneer contributors in this field, the most outstanding was Alexander Graham Bell, who invented, and patented in 1876, the first telephone capable of practical use. As early as 1874 he had conceived the correct principle of telephone transmission, which he later stated as follows: "If I could make a current of electricity vary in intensity precisely as the air varies in density during the production of sound, I should be able to transmit speech telegraphically."

This conception of an undulatory current corresponding to a speech wave formed the foundation for the entire telephonic art. Earlier workers, notably C. G. Page in the United States (1837) and Charles Bourseul in France (1854), had devised methods employing the make-and-break principle of the telegraph for transmitting the pitch of sounds, but not articulate speech, to a distant point.

Philipp Reis came closer. Working at Frankfurt, Germany, in 1860 and subsequent years, he devised an apparatus using at the transmitting end a diaphragm structure something like that of the human ear to

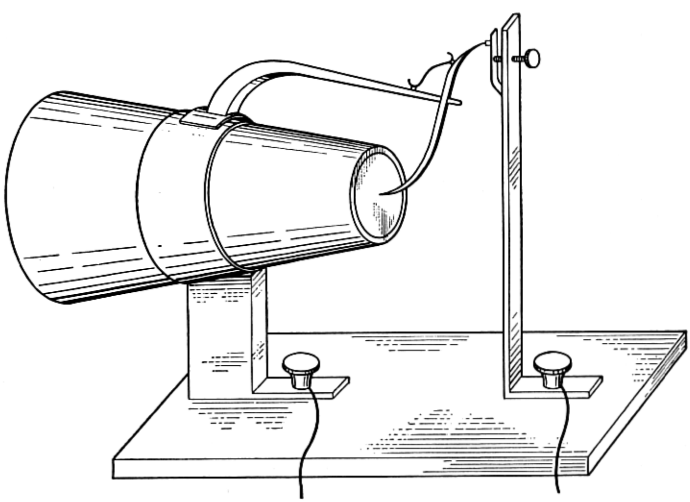


Fig. 1 — Transmitter of Philipp Reis, 1861 or 1862.

control an electric current (Fig. 1). At the other end of the circuit this produced audible tones by controlling the magnetization of a needle whose changes of length, in accordance with the magnetostrictive effect discovered by Page, vibrated a sounding board. In later apparatus an electromagnet was substituted for the needle. Reis's mechanism, like others before and after, included the important feature of deriving the electrical power for transmitting sound by making the sound power control the current from a battery.

Reis had some comprehension of the requirement for electrical transmission of speech, for he noted in his memoir on telephony the need "to set up vibrations whose curves are like those of any given tone or combination of tones" (S. P. Thompson translation). Though his apparatus served primarily to reproduce tones by the make-and-break scheme, he did, by extremely delicate adjustment, succeed in reproducing articulate sounds quite imperfectly. Reis seems not to have realized, however, that this success resulted because his apparatus could, over a very narrow range of speech volume, operate on the principle of changing an electric current in accordance with the voice wave by varying a loose contact, in this case a spring contact between platinum electrodes. His understanding of his own apparatus is indicated by his statement that "each sound vibration effects an opening and a closing of the current." About 20 years later, the German patent office after careful investigation decided that Reis's instrument was not a "speaking telephone."

In the following years attempts were made by other workers (*e.g.*, the Italians A. Meucci and I. Manzetti), but without full realization of the requirements for articulate speech.

Bell's approach was different. In the summer of 1874 the idea of the "electric speaking telephone" became complete in his mind. He described to his father a form of apparatus consisting of a strip of iron attached to a membrane which, when actuated by the voice, would vibrate in front of an electromagnet, thus inducing an undulatory electric current theoretically capable of transmitting speech. At the receiving end a similar device could be used in reverse to reproduce the voice. But Bell doubted that the current generated by the voice would be strong enough to be useful, and for almost a year he made no attempt to construct the apparatus.

On June 2, 1875, while working in Boston on multiplex telegraph apparatus, Bell heard over an electric wire a sound corresponding to the twang of a steel spring at the other end. Recognizing this as a manifestation of the undulatory current principle, he gave his assistant, Thomas A. Watson, instructions for embodying it in a model (Fig. 2)

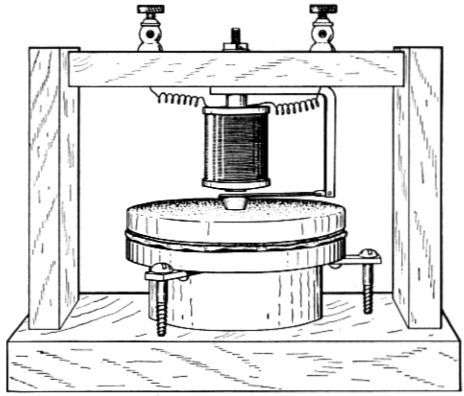


Fig. 2 — "Gallows frame" transmitter of Alexander Graham Bell, June 3, 1875.

of a telephone. The transmitter and receiver were of the electromagnetic type described a year before, and in between was a circuit which included an electric battery. This apparatus transmitted speech sounds the next day, June 3. Bell filed his application for a U.S. patent on Feb. 14, 1876 (Fig. 3). Further experiments produced an instrument (Fig. 4) which on March 10, 1876, transmitted the first complete sentence: "Mr. Watson, come here; I want you."

A few hours after Bell filed his application for patent, Elisha Gray filed a caveat (*i.e.*, a notice of intent to perfect his ideas and file a patent application within three months) for an electric telephone. Gray described a "liquid transmitter," somewhat similar to one patented by Thomas A. Edison for telegraphy in 1873. In Gray's transmitter a voice-actuated diaphragm varied the electrical resistance, and hence the current, by changing the depth of immersion of a rod in water. Bell in

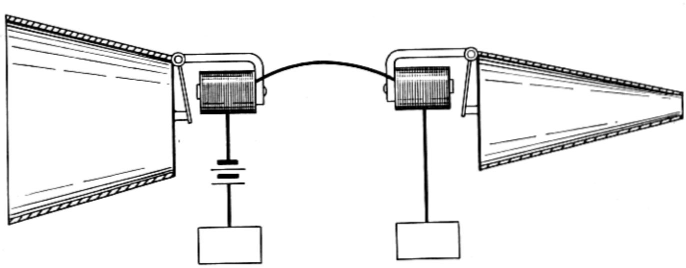


Fig. 3 — Electromagnetic transmitter (left) and receiver (right) illustrated in Bell's first telephone patent, filed Feb. 14, 1876.

his application mentioned the possibility of a similar liquid transmitter, and later used it for his historic summons to Watson. The variable-resistance principle, which subsequently, in the form of a variable carbon contact, proved of vital importance to telephone transmission, makes it possible to obtain an electric wave which is an amplified copy of the sound wave. Like Bell's receiver, Gray's was of the electromagnetic type, similar to one he had patented in Great Britain in July 1874 and in the U.S. in July 1875.

In view of Bell's prior filing of a patent application, the patent for the telephone was issued to him on March 7, 1876. Gray's status as to the invention of the telephone is best set forth in his own words, written to Bell on March 5, 1877: "I do not claim even the credit of inventing it." The claims of Gray, Daniel Drawbaugh and others were subsequently threshed out in prolonged litigation, involving about 600 separate suits, which finally resulted in Bell's patent being upheld in a divided vote by the Supreme Court of the United States.

Bell's first transmitter employing electromagnetic induction, while sound enough in theory, delivered such feeble electrical currents as to be inadequate for general application. The liquid transmitter afforded considerable improvement, but this too had drawbacks. The final essential element for a satisfactory working telephone was the variable-

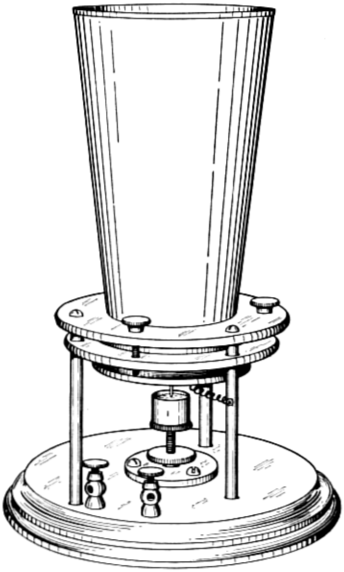


Fig. 4 — Liquid transmitter used by Bell on March 10, 1876.

contact carbon transmitter, due in large measure to Thomas A. Edison, as discussed below.

INTRODUCTION AND GROWTH

United States

The development of the telephone business in the United States was undertaken by a group of Bell's backers, under the leadership of Thomas Sanders and Gardiner G. Hubbard. They began by renting or lending telephones in pairs to individuals for local communication. The instruments were extremely crude. Connection between them was made by a circuit consisting of a single iron wire with ground return, and transmission, which was uncertain and poor at best, was possible for only a few miles. Initially there were no switchboards to interconnect a number of users. These came into being in 1877 and 1878.

It was on March 25, 1878, that Bell made a bold prediction that became a charter for the founders of the telephone business:

"It is conceivable that cables of telephone wires could be laid underground, or suspended overhead, communicating by branch wires with private dwellings, country houses, shops, manufactories, etc., etc., uniting them through the main cable with a central office where the wires could be connected as desired, establishing direct communication between any two places in the city. Such a plan as this, though impracticable at the present moment, will, I firmly believe, be the outcome of the introduction of the telephone to the public. Not only so, but I believe, in the future, wires will unite the head offices of the Telephone Company in different cities, and a man in one part of the country may communicate by word of mouth with another in a distant place.

"I am aware that such ideas may appear to you Utopian. . . .Believing, however, as I do that such a scheme will be the ultimate result of the telephone to the public, I will impress upon you all the advisability of keeping this end in view, that all present arrangements of the telephone may be eventually realized in this grand system. . . ."

The owners of the telephone patent early incorporated their business, and funds were raised for its progressive development, under the leadership of Theodore N. Vail, who became general manager in 1878. It was recognized that telephone performance is a matter of mutual concern to users, and the practice was established of leasing telephones instead of selling them.

Within ten years after the issuance of the Bell patent, the organization of the Bell Telephone system had assumed something close to its present form. The local systems were gradually brought together into regional companies operating throughout a state or several states. The systems of these regional companies were linked together by long-distance circuits operated by the American Telephone and Telegraph Company. This company, through ownership of stock in the regional companies, became the parent company of the Bell System.

It soon became evident that standardization of equipment and centralized research on improvements are essential to telephone progress. Accordingly, the Western Electric Company was acquired in 1882 as chief manufacturer and supplier for the Bell System, as well as to conduct research and development. In 1925 the Bell Telephone Laboratories was organized to take over the expanding research and development activities for the system. The 1,600,000 owners of shares in the American Telephone and Telegraph Company in the mid-1950s constituted the largest number of public owners for any one corporation in the world.

After the expiration of the basic telephone patents, many independent telephone companies, not affiliated with the Bell System, sprang up all over the country. Competition became so intense that in many localities there were two companies sharing the business. As this became an increasing source of inconvenience and expense to the public, the service was unified through acquisitions and mergers so as to leave a single company, either Bell or non-Bell, operating in each area. Provision was made for interconnecting the facilities of non-Bell companies with those of the Bell System, thus making possible the interconnection of nearly all telephones in the United States, as well as connections to the rest of the world.

Service and rates are regulated by state utility commisions and the Federal Communications Commission.

There were about 60,000,000 telephones in the U.S. early in 1957 or approximately 1 telephone for every 3 persons in the country. About 82 per cent of these telephones were served by the Bell System, comprising the American Telephone and Telegraph Company and its 20 operating subsidiaries, and 2 associated but noncontrolled companies (the Southern New England Telephone Company and the Cincinnati & Suburban Bell Telephone Company). The remaining telephones were served by about 4,200 independent companies and additional thousands of rural or farmer lines, virtually all of which connect with the Bell System. The total investment in telephone plant and equipment was nearly $20,000,000,000, of which 87 per cent belonged to the Bell System. Telephone traffic averaged over 216,000,000 conversations daily in 1956. Over 800,000 persons were employed by the telephone industry,

TABLE I—TELEPHONE DEVELOPMENT IN THE U. S.

End of year	Number of telephones	Telephones per 100 population
1880	47,900	0.09
1890	227,900	0.36
1900	1,355,900	1.76
1910	7,635,400	8.20
1920	13,329,400	12.39
1930	20,202,000	16.34
1940	21,928,000	16.52
1950	43,004,000	28.09
1954	52,806,000	32.21
1956	60,190,000	35.45

including more than 100,000 employed in the manufacture of telephone equipment and about 10,000 by the Bell Telephone Laboratories.

The growth of the telephone industry in the United States is shown in Table I.

Great Britain

Bell visited England and Scotland on his wedding trip in 1878 in the hope of developing a demand for the telephone. Despite the able support of Lord Kelvin, Sir William Preece and others, he aroused little public interest. He did, however, demonstrate his invention to Queen Victoria, who asked to purchase a pair of telephones, and instead was presented with two instruments done in ivory. Stimulated by this royal recognition, the first telephone exchange was opened in London in 1879 with seven or eight subscribers. Several telephone companies were organized in various parts of Great Britain, but in 1880 the British courts held that the telephone system was legally a telegraph system under an antecedent law which made the telegraph a government monopoly under the postmaster general. The government officials, reluctant to assume the risks involved in developing this new form of communication, issued licenses on a royalty basis to several private companies, which were later consolidated into a single company. A few municipal telephone systems were also established under license.

As the potentialities of telephone communication began to be appreciated, the government gradually took over the service. In 1896 the post office purchased the long-distance lines, and in 1902 it began establishing in London its own local telephone exchanges which were interconnected with those of the privately owned company. Finally, on Jan. 1, 1912, the post office acquired all the private telephone properties. Since then the post office has operated practically all telephones in Great Britain and Ireland. When the Irish Free State was established, the British post office transferred to the Free State government its telephone system in southern Ireland.

At the end of 1956 there were about 7,214,000 telephones in the United Kingdom, which was more than in any other European country, and represented 1 telephone per 7 persons. The British post office maintains a large research and development organization. Telephone apparatus is supplied by private companies that manufacture to post office specifications.

Germany

In Germany the telephone was a government monopoly from the beginning. Heinrich von Stephan, postamaster general and manager of the imperial telegraphs, when he learned about Bell's invention from an article in the *Scientific American*, ordered models for trial. After successful experiments at distances up to 90 mi. (Berlin-Magdeburg), he suggested on Nov. 9, 1877, to Prince Otto von Bismarck, the imperial chancellor, that the telephone be used as an adjunct to telegraph service in rural post offices where there was not sufficient traffic to justify a trained telegraph operator. Within two years 800 villages were thus connected.

So it came about that in Germany the first public use of the telephone was for long-distance communication, telephones being found only in government post offices. The situation was therefore the reverse of that in the United States and Britain, where local exchanges came first. Later, as public demand forced the issue, exchange service was gradually introduced, starting in the larger German cities. In the German states of Bavaria and Württemberg, the telephone systems were operated by the state administrations until 1920, when they were transferred to the German post office.

At the beginning of 1957 the Federal Republic of Germany, commonly known as West Germany, had the second largest telephone system in Europe, with 4,323,000 telephones or about 1 telephone per 12 persons. The German Democratic Republic, commonly known as the eastern or Soviet zone, had 1,067,000 telephones or about 1 telephone per 17 persons.

France

In France the telephone was first exhibited at the Paris world's fair in 1878, where it attracted little interest. The next year, however, the French telegraph officials, unwilling themselves to pioneer in this new field, granted concessions to several private companies which later consolidated into the Societé Générale des Téléphones. This company initiated public telephone service in Paris in 1881 and subsequently in other cities. Starting in 1883, the French government established exchanges in various centers. In 1889 the government took over the entire private system, and after that time operated the telephone service. With 3,313,000 telephones (over one-fourth of these in Paris) at the beginning of 1957, the French telephone system was third in size among those of Europe.

Switzerland

In Switzerland a privately owned telephone system was established under government concession in Zürich in 1880, while the government itself opened exchanges in Berne and Basel in 1881. Thereafter the government proceeded rapidly to establish new exchanges, and in 1886 purchased the Zürich system. After that time the Swiss government operated all telephones. At the beginning of 1957 there were about 1,294,000 telephones, amounting to almost 1 telephone for every 4 persons.

Scandinavia

The Scandinavian countries have achieved a high degree of telephone development. In Sweden, the International Bell Telephone Company of New York opened exchanges in Stockholm and Göteborg in 1880, and not long after in Malmö and elsewhere. In 1883 a competing telephone company was set up in Stockholm under the enterprising leadership of H. T. Cedergren. Co-operative telephone associations were established in Göteborg and in many rural communities. After a strongly competitive phase, in which the government participated, virtually all telephones were taken over by the state during the period 1890–1923. At the beginning of 1957 the Swedish Telecommunication administration operated about 2,312,000 telephones. The telephone density, approximately 1 telephone for every 3.2 persons, was higher than anywhere except in the United States.

The Swedish administration not only maintains a development organization, as do most other countries in Europe, but it is unique among European telephone administrations in possessing factories for production of telephone equipment.

In Norway the International Bell Telephone Company in 1880 secured franchises for Oslo and Drammen. The next year local companies established exchanges in several cities, and a competing system in Oslo. Within ten years, largely through local enterprise, the telephone came to hold much the same place in Norwegian rural life that it does in the sparsely settled districts of the U.S. Ultimately the state acquired the more important local systems, and at the end of 1956 about 92 per cent of the country's 615,000 telephones were government-operated.

In Denmark, likewise, the telephone was introduced by private enterprise, the government interposing no serious difficulties. Gradually numerous small systems were consolidated into several relatively large organizations. The principal one is the Copenhangen Telephone Company, a stock company in which the government owns a controlling interest. Nearly half of Denmark's 923,000 telephones at the beginning of 1957 were in the city of Copenhagen. Denmark had at that time about one telephone for every 5 persons.

Belgium and the Netherlands

In Belgium telephone exchanges were first established in various cities by private concessionaires. In 1896, however, the telephone system became a complete government monopoly, and has remained so. At the beginning of 1957 there were 931,000 telephones. Private grants formed the initial pattern in the Netherlands also. As competition with the government telegraphs became apparent, the private telephone systems were integrated into a single government system, which at the end of 1956 comprised about 1,229,000 telephones.

Austria, Italy and Spain

Austria followed the typical European course, starting with private companies which later were bought in so as to create a government monopoly. There were 540,000 telephones at the end of 1956 or about 1 telephone for every 14 persons.

In Italy the story is somewhat different. To begin with, concessions were granted to private companies and in a number of important cities competititive situations arose. As the disadvantages of competition manifested themselves, consolidation was effected either voluntarily or by the dictates of local authorities. Partly as a result of onerous regulations, telephone development failed to keep pace with that in other European countries. In 1925 the structure of Italian telephone service assumed essentially the form that obtains today. Five concessionary companies operate local and toll service, each within one of the five zones into which Italy has been divided for this purpose. These companies are privately operated, although the government participates in the ownership. The government operates long-distance interconnecting service as well as the landline portion of international service. Growth in recent years has been rapid, and at the end of 1956 Italy had 2,609,000 telephones.

In 1924 Spain granted a concession to a subsidiary of the International Telephone and Telegraph Company of New York to provide a nation-wide telephone system to supersede the previous government- and privately-owned systems which had attained only a limited development. There were operating difficulties during the Spanish civil war, and in 1945 the government purchased the International Telephone and Telegraph operating interest. At the end of 1956, 1,199,000 telephones were operated by a private company in which the government held a controlling interest.

U.S.S.R. and Satellites

In the mid-1950s no recent official statistics were available on the telephone systems of the U.S.S.R. and satellite countries, but development there had lagged far behind that in western Europe.

Canada

Canada, divided by natural barriers and with most of its population concentrated near the long southern border, nevertheless at the end of 1956 ranked next after the United States and Sweden in density of development, having 1 telephone for every 4 persons and a total of 4,502,000 telephones. Moreover, Canadians led the world in use of the telephone, making 481 calls per person in 1956, compared with 455 for Sweden and 426 for the U.S. Most of the telephones in Canada were at that time administered by seven private companies, which were banded together as the Trans-Canada system to furnish through service.

Latin America

Early development of telephony in Latin America was slow, for various reasons. Colonization by different European countries, superposed on the native background, led to a wide variety of languages and cultures. Tropical areas, mountainous regions and other natural barriers tended to limit development to the more populous isolated areas. In many cases foreign capital was obtained through private concessions, but certain countries where this was done followed the European plan of subsequent transfer to government ownership.

At the end of 1956 Argentina, with 1,155,000 telephones, led the Latin-American countries in telephone development and Brazil, with 843,000, came next. Telephone systems of some size in Latin America were operated by subsidiaries of certain companies located in foreign countries, as follows: International Telephone and Telegraph Corporation, in Brazil, Chile, Peru, Cuba and Puerto Rico; the L. M. Ericsson Company, in Argentina and Peru; Cables and Wireless, Ltd., in Peru. Mexico's largest system was owned jointly by the I. T. & T. Corporation and the L. M. Ericsson Company. During the five-year period ending with 1956, the percentage growth of telephones in South America exceeded that in North America.

Elsewhere

Telephone development in the rest of the world may be summarized with the statement that, at the end of 1956, while some sort of telephone service is to be found almost everywhere, systems of substantial size are limited to Japan (3,487,000 telephones), Australia (1,762,000), South Africa (766,000), New Zealand (568,000) and Finland (486,000). Asia, with the lowest average level of telephone development, exceeded all the other continents in percentage growth during the five-year period ending with 1956.

Growth Factors

The rapidity of telephone growth and the intensity of development in different parts of the world were affected by a variety of factors, among which may be noted scientific advance, economic status, culture, degree of industrialization, size of market, linguistic and dialectic diversities, physiography, type of ownership, managerial enterprise and political and military considerations. Although the qualitative influence of these factors upon telephone development can frequently be observed, it is impracticable in any particular situation to assign specific weights to them. Sometimes cause and effect are inseparable. Civilization begets telephones, and telephones beget civilization.

Telephone Statistics

At the end of 1956 there were approximately 110,000,000 telephones in the world, 55 per cent of these in the United States. Any one of 106,000,000 telephones, scattered throughout the world, could be connected to a telephone in the U.S. Almost 70 per cent of the world's telephones were privately owned, the remainder government-owned.

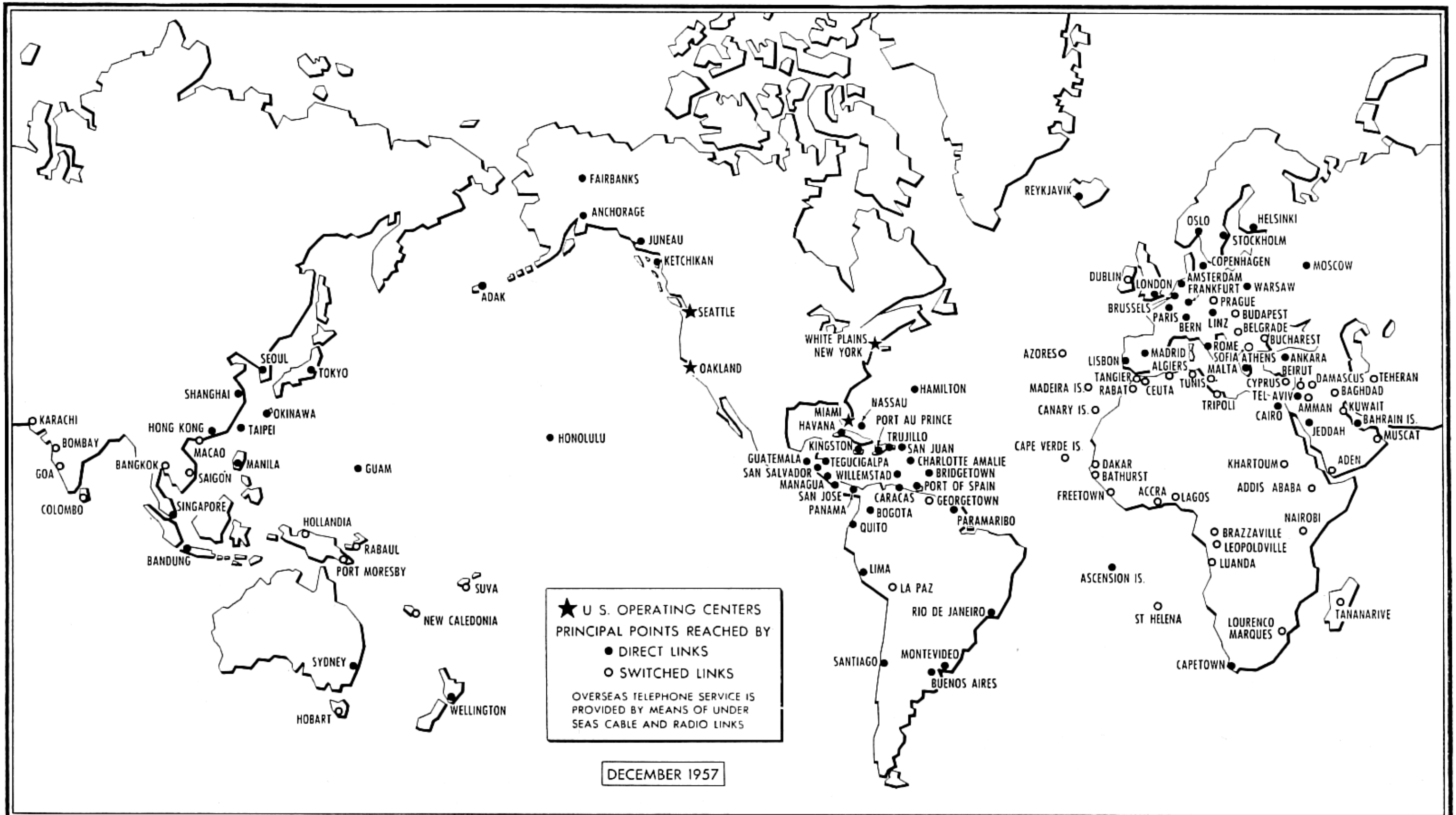


Fig. 5 — U. S. overseas telephone circuits in the mid-1950s.

Table II—Countries with More than 1,000,000 Telephones in Service on Jan. 1, 1957

Country	Number	Country	Number
United States	60,190,000	Sweden	2,312,000
United Kingdom	7,219,000	Australia	1,762,000
Canada	4,502,000	Switzerland	1,294,000
Germany, Federal Republic	4,323,000	Netherlands	1,229,000
Japan	3,487,000	Spain	1,199,000
France	3,313,000	Argentina	1,155,000
Italy	2,609,000	Germany, Democratic Republic	1,067,000

The distribution of telephones by principal countries is shown in Table II. Major U.S. overseas telephone connections are shown in Fig. 5.

Among the world's cities, Washington, D.C., led in density of telephone development, with 65.3 telephones per 100 population in 1956. Others ranking high among cities of more than 100,000 population included: Los Angeles, 64.9; San Francisco, 58.2; Stockholm, 54.8; Berne, Switz., 54.1; Basel, Switz., 55.9; Geneva, Switz, 53.5; Hartford, Conn., 53.2; Pasadena, Calif., 52.2; Wilmington, Del., 51.8; and Denver, Colo., 48.5.

ITU and CCITT

Much of the progress in international telephone communication may be attributed to the work of international co-ordinating bodies. This work now centers in the Union Internationale des Télécommunications (UIT), called in English the International Telecommunication Union, abbreviated ITU. This organization, now an agency of the United Nations, was originally founded in 1865 as the Union Télégraphique Internationale. The purposes of this organization as set forth in its charter are "To maintain and extend international co-operation for the improvement and rational use of telecommunication; to promote the development of technical facilities and their most efficient operation, in order to improve the efficiency of telecommunication services, increase their usefulness, and make them, as far as possible, generally available; to harmonize the actions of nations in the attainment of those common ends." On July 1, 1954, the ITU had a membership of 90 countries or territories. The activities of the ITU and its constituent bodies are financed by contributions from member governments.

Of special interest and importance are three permanent and essentially autonomous organs of the ITU: (1) the Comité Consultatif International Téléphonique (International Telephone Consultative Committee), abbreviated CCIF, founded in 1924; (2) the Comité Consultatif International Télégraphique (International Telegraph Consultative Committee), abbreviated CCIT, founded in 1925; and (3) the Comité Consultatif International des Radio Communications (International Radio Consultative Committee), abbreviated CCIR, founded in 1927.

For implementing its work, each of these three international consultative committees has organized a number of study groups covering different phases of activity. A plenary assembly distributes questions to be investigated by the study groups. These work by correspondence or by meeting and submit their findings to the succeeding plenary assembly which studies and discusses them and makes recommendations. Ordinarily the recommendations take the form of directives or rules which, without being mandatory, are usually observed by the technical and operating services of the government administrations and private operating agencies of the countries belonging to the union. The director of the consultative committee co-ordinates the work of the study groups, of the plenary assembly and of the committee as a whole.

The work of these three committees has emphasized the importance of good engineering and transmission standards to world-wide communication service and has gone far in bringing about the introduction of such standards. In particular, the CCIF has given exhaustive consideration to problems of transmission and interference, frequency bands and allocations, standards of telephone performance and questions of suitable rates and classes of service, all of which has contributed to effective international long-distance telephony. On Jan. 1, 1957 the CCIF and CCIT merged to form a new organization known as the CCITT (Comité Consultatif International Téléphonique et Télégraphique.

TECHNICAL DEVELOPMENT

The first telephones were extremely crude; it was barely possible to talk over them. The problems of transmitting speech over substantial distances were not understood, or even visualized. Nor was there the slightest comprehension of the complications involved in interconnecting large numbers of telephones. Far-reaching developments on many fronts were needed to bring the art of telephony to its present state of perfection.

One indispensable phase was the progressive improvement of telephone station instruments as to quality and loudness of speech, as well as convenience and cost. Concurrently, it was necessary to develop telephone lines and circuits that could transmit speech currents reliably, without appreciable impairment or interference, and economically, for short or long distances. These two advances are sometimes grouped under the single term, transmission development. Through such development, telephone conversation has, except under adverse conditions, become practically effortless.

Another essential was the development of switching mechanisms whereby any two telephone instruments in a large system could be connected together certainly, rapidly and economically. This part of the advance is referred to as switching development. Progress in these areas came about gradually in different countries, along generally similar but not identical lines, and with, in many instances, substantial time differences.

Station Instrumentalities

The station set at the premises of a telephone customer normally consists of a transmitter, which converts the speech waves in the air into their electrical replicas; a receiver, which performs the reverse operation of converting the incoming electrical waves into sound waves; a transformer (formerly called an induction coil) designed to increase the effectiveness of the transmitter and to permit full duplex operation, *i.e.*, use of a single pair of wires for speech in both directions, without requiring a switch to change from talking to listening or vice versa; a bell or equivalent summoning device; a switch hook to control connection of the set to the customer's line; and various associated items. In automatic switching systems the station set also includes a device, such as a dial, for generating signals to actuate the switching mechanism.

Bell's original electromagnetic transmitter served also as the receiver, the same instrument being held alternately to the mouth and the ear. An important forward step was the invention by Émile Berliner in 1877, and by Thomas A. Edison later in the same year, of different forms of transmitters utilizing variable-contact resistance between two solid electrodes connected in a battery circuit. Berliner employed metallic electrodes, while Edison used semiconducting materials, particularly plumbago (*i.e.*, graphite). Berliner also introduced the induction coil into the transmitter circuit in 1877.

The principle of the microphone contact, which underlay both the Berliner and Edison transmitters, was elucidated by David E. Hughes in England in 1878. By virtue of this principle, energy from a battery is controlled by the voice waves so that the telephone transmitter acts as an amplifier as well as a converter of sound waves. The first recorded recognition of amplification through a microphonic contact seems to be found in a German patent of Robert Lüdtge, issued Jan. 12, 1878.

A transmitter in which granular carbon was used for the variable contact was invented in 1878 by Henry Hunnings, an English clergyman. Edison invented a transmitter whose carbon granules were obtained from anthracite coal, and Anthony C. White in 1890 invented the solid back transmitter, using a "button" of granular carbon placed between a fixed electrode and a diaphragm-actuated movable one. White's transmitter incorporated all the basic features of the modern telephone transmitter, though great improvements in efficiency (up to a thousand-fold amplification of speech sounds), naturalness, resistance to aging and other features have resulted from continuing research and development. Extensive studies of the properties of speech and hearing have contributed to this result.

Modern telephone receivers utilize the same basic principles found in Bell's original instrument. Fundamentally, the receiver consists of a permanent magnet having pole pieces wound with coils of insulated fine wire, and a diaphragm driven by magnetic material which is supported near the pole pieces. Speech currents passing through the coils vary the attraction of the permanent magnet for the diaphragm, causing it to vibrate and produce sound waves. Through the years the design of the electromagnetic system has been continuously improved to provide better talking qualities. In a new type of receiver, introduced in the

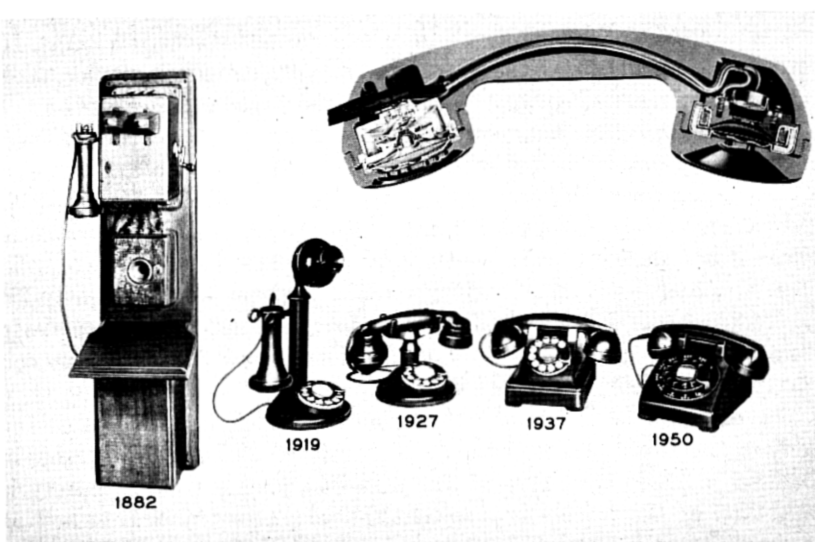


Fig. 6 — The evolution of telephone set design in the Bell System, including the approximate date when each design was adopted. *Inset:* Cross section of a modern handset.

United States in 1951, the diaphragm, consisting of a central cone and ring-shaped armature, is driven as a piston to obtain efficient response over a wide frequency range.

In early telephone sets a hand-cranked generator, or so-called magneto, was used for signaling the operator, and local dry batteries supplied power to the transmitter. A centralized battery arrangment for signaling was invented in 1880 and one for both talking and signaling in 1886. With the gradual introduction of this common battery system, magneto telephone sets were largely superseded.

The first suggestions for mounting a telephone transmitter and receiver on a common handle, thus forming what is now known as a handset, were made by two Englishmen, Charles A. McEvoy and G. E. Pritchett, in 1877. Starting in 1878, a type of handset devised by Robert G. Brown was used by boy operators in the Gold and Stock telephone exchange in New York city. Handsets for customers' use were introduced in France about 1882 and spread quickly in Europe. Initial difficulties in meeting satisfactory transmission standards with the handset arrangement were gradually overcome and most modern instruments are of this type.

Methods of connecting the transmitter and receiver to the line have likewise been gradually improved. Starting with work by George A. Campbell, arrangements known as anti-sidetone circuits have been developed whereby most of the electrical energy generated in the transmitter is directed toward the distant station, with a minimum entering the speaker's receiver.

Apart from the basic telephone instrument, special customer equipment and arrangements are provided to meet individual requirements of various kinds. Telephone sets are available which permit the user to hold a conversation without lifting the receiver, a small microphone being used to pick up the voice and a small loud-speaker to reproduce the incoming speech. There are loud gongs or other signaling devices for noisy locations, amplifiers for persons with subnormal hearing, automatic telephone-answering devices, arrangements for recording conversations, loud-speakers for paging service, etc.

Telephone pay stations installed in public or semipublic locations provide a coin telephone set which includes, in addition to the usual station equipment, a coin collector having one or more slots designed to accept legitimate coins and reject slugs or spurious coins. The coins, in passing down their respective slots, strike distinctive gongs whose tones permit an operator to supervise the deposits. Many coin collectors are arranged to hold the coins in suspension in a hopper, with means provided whereby the suspended coins can be collected or refunded, depending on whether or not the desired connection is completed.

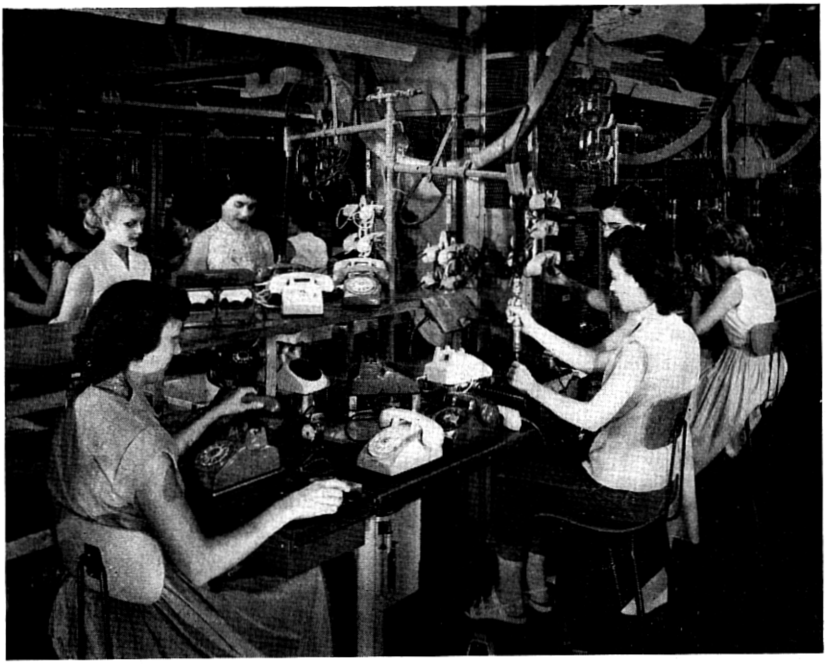


Fig. 7 — Assembly and testing of telephone sets.

Key telephone systems, affording greater flexibility of telephone usage than a single station set, are frequently used in business offices and residences. Combinations of push-button, turn-button or lever-type keys, installed on a desk or table or mounted integrally in the base of a telephone set, can be arranged to perform a variety of functions, particularly where two or more lines and a number of stations are involved. Thus a telephone may be connected to any of several lines, a call may be held on one line while conversation proceeds on another, etc.

Telephone Lines

Telephone circuits are furnished principally by wire lines, although radio is used to a moderate extent. Telephone lines comprise a network of wires which interconnect individual telephone stations, central offices and communities. These wire lines are of two forms — cable and open wire. The usual type of cable consists of insulated copper wires, twisted together and usually covered with a protecting sheath. Open-wire lines consist of bare wires, generally of copper, fastened to insulators which are supported on poles at some distance above ground, commonly on pins in crossarms.

Following previous telegraph practice, the first telephone circuits utilized a single overhead wire, usually iron, with ground return. An important early improvement was the development by Thomas B. Doolittle in 1877 of hard-drawn copper wire, giving good tensile strength together with improved electrical conductivity. The advantages of a two-wire or so-called metallic circuit in reducing noise and interference were soon realized. It was found also that by transposing the wires, *i.e.*, interchanging their positions, a number of circuits could be carried on a single pole line without excessive interaction which would permit the conversation on one circuit to be heard on another. These several features made possible a successful open-wire telephone line between Boston and New York in 1885.

Early in telephone history, as the number of open-wire circuits strung on poles and rooftops in the large cities began to reach the point of impracticability, methods of compacting the lines in overhead or underground cable were tried. At first the wires were placed in pipes and sealed against moisture with oil, paraffin or asphaltum. Means were soon developed whereby lead, heated to plasticity, could be extruded over a core of conductors. The introduction of dry paper as insulation for the conductors completed the foundation for the modern telephone cable.

Research and development covering many materials and processes made it possible to increase the number of pairs in a full-sized local cable from a maximum of 50 in the year 1888 to 2,121 in 1955. This increase was accomplished largely by reducing the size of the copper wires, from 25 lb. per wire mile in 1888 to 4 lb. in 1955. Following World War II, new types of cable sheath were developed in order to reduce cost and lessen dependence on lead supply. One form uses thin layers of aluminum and steel covered with polyethylene.

In a typical urban or suburban installation, insulated wires from each customer's premises extend to a distribution cable which in turn connects to a feeder cable leading to the central office. In densely built areas the feeders are generally placed in underground ducts; elsewhere, overhead. Circuits between central offices, known as trunks, are provided in trunk cables which usually employ larger wires than those leading to customer stations.

The network of lines which interconnect approximately 73,000 communities in the U.S. included in the mid-1950s approximately 31,000,000 miles of wire on 230,000 miles of route. About 91 per cent of the wires were in cable, the remainder open wire. For the rest of the world, the per-

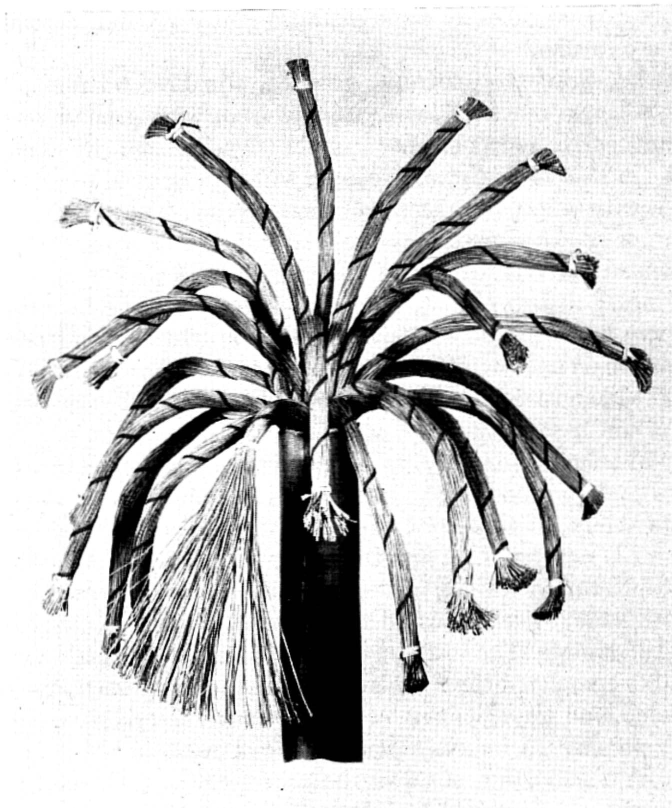


Fig. 8 — Multiple-unit telephone cable, consisting of 21 groups, each comprising 101 pairs of 26-gauge wires.

centage of long-distance facilities furnished by cable ranges from nearly 100 per cent in a few countries to a very low figure in the less populated regions. Since cable is virtually storm-proof, it affords much greater reliability than open wire.

A type of long-distance cable common in the U.S. employs conductors 36 mils in diameter, weighing 20 lb. to the mile (no. 19 AWG gauge). In making this cable, two paper-insulated wires are first twisted together to form a pair; then a quad is formed by twisting two pairs together. This twisting aids in the prevention of crosstalk (*i.e.*, overhearing) between different pairs. In European toll cables, four conductors are usually twisted together to form a spiral four or star quad. In either case the quads are grouped together and enclosed by the sheath. Such a cable may be supported aerially or placed in an underground duct, or, with a suitable protective covering of jute or steel tape, may be buried in the ground. A special type of cable used for coaxial systems is discussed under *Carrier Systems* below.

Phantoms

Around 1900 the principle of "phantoming" two pairs of wires was introduced. The original idea of phantoming was devised by Frank Jacob in 1882, and the present method by John J. Carty in 1886. The phantom arrangement makes it possible to derive from two pairs of wires a total of three telephone circuits. The additional circuit, called the phantom, is obtained by using the two wires of each pair in parallel as a side of the phantom. To render this scheme practical, efficient balanced transformers were needed for the end connections, and transposition arrangements to keep the crosstalk between the three circuits within tolerable bounds. The phantom principle came to play an important part in both open-wire and cable plant. Because the presence of phantoms makes high-frequency transmission quite difficult, the advent of carrier systems has greatly curtailed the use of phantoms for long-distance circuits.

Loading

As speech currents pass along a line their strength decreases (a process referred to as attenuation), so that after some distance they become too weak to actuate a receiver properly. Studies by A. Vaschy (1889) and Oliver Heaviside (1893) developed the theoretical possibility of improving the transmission efficiency of telephone lines by artificially increasing their inductance. Various investigators speculated on the practicability of approximating the beneficial effect of an increase in uniformly distributed inductance by introducing in the line concentrated or lumped inductance in the form of low-resistance loading coils. Finally, in 1899, Michael I. Pupin and George A. Campbell (working independently, Pupin having a slight priority) discovered that the key to the problem was the spacing of the loading coils. By providing at least pi (*i.e.*, about 3.14) loading coils per wave length at the highest frequency to be transmitted, a substantial reduction in the attenuation of the speech waves is obtained. Thus a cable circuit may, by means of coil loading, be made to transmit telephonic currents as efficiently as a non-loaded one whose conductors weigh many times as much.

Another way of adding inductance to a cable circuit was proposed by Carl Emil Krarup of Copenhagen, his idea being to wind helically along the copper conductor a fine wire of soft iron. A cable with this continuous loading was placed between Elsinore and Helsingborg in 1902. While continuously loaded cables have proved of some importance for submarine applications, coil loading has been almost universally preferred for loaded land cables.

By 1913 coil loading made it possible to extend the useful range of open-wire circuits to approximately 2,000 miles and to employ underground cable to connect Washington, D.C., and Boston via New York City. After electron tube amplifiers became available, open-wire loading was largely abandoned, but loading is still extensively applied on cable circuits used for voice frequencies, and especially on local trunk circuits.

Satisfactory loading requires that the loading coils have very low energy losses in their magnetic cores and copper windings. The toroidal-shaped cores of modern loading coils make use of a powdered magnetic alloy whose particles are individually insulated, compressed under high pressure and then usually heat treated to develop optimum magnetic properties. Progressive improvement of magnetic core materials has brought about large reductions in the size and cost of loading coils, as well as improved performance. A core material commonly used in the U. S. consists of an alloy of nickel, iron and molybdenum known as molybdenum permalloy, discovered by Gustav W. Elmen. In Europe powdered iron cores of somewhat larger size are employed.

Electron Tubes and Repeaters

For years the range of telephony was severely limited by loss of energy due to dissipation along wire lines, or to spreading in the case of radio waves. The idea of inserting one or more repeaters in a telephone line for the purpose of reinforcing or amplifying the telephonic currents from some local source of energy is almost as old as the telephone itself, but many years elapsed before the quest for a satisfactory repeater achieved success. In a so-called mechanical repeater, tried in 1904, inertia of the moving parts was found to present inherent limitations. Subsequently H. E. Shreeve developed a repeater employing carbon-contact amplification which was capable of practical use. The real solution to the amplification problem, however, was found in the device invented by Lee De Forest in 1906, which he called the audion, and which is now known as a three-electrode vacuum tube or electron tube, or in England as a valve. In its original form as used in radio telegraphy this tube was unsuited for telephone purposes. Research by Harold D. Arnold, Irving Langmuir and others showed that a major requirement for adequate performance in an amplifier was the creation of a high degree of vacuum inside the tube envelope. By 1914 satisfactory high vacuum tubes were produced. Using telephone repeaters with amplification supplied by vacuum tubes, telephone service between New York and San Francisco was inaugurated in 1915. So telephony at last found the means for conquering distance, and it was this application of the vacuum tube in the telephone business that ushered in the electronic age.

Continuing development work brought about many improvements in vacuum tube repeaters. Efficient circuits and auxiliary equipment were devised for utilizing the amplifier element and associating it with the line circuits. The life of the repeater tube most commonly used in 1917 was about 1,000 hours, whereas standard tubes of a type introduced in 1935 have a life of about 90,000 hours, equivalent to more than ten years of continuous operation. In addition, the power required to heat the tube filaments was reduced to one-tenth that required in 1917.

New types of tubes with four or five elements, especially adapted for use in carrier and radio systems, were developed also. The role of vacuum tube repeaters in modern telephony is evidenced by the fact that in 1955 there were in the telephone plant in the U. S. about 480,000 voice and carrier repeaters using about 5,000,000 vacuum tubes.

With repeaters available, transmission defects of different kinds became increasingly apparent. The lines, particularly if loaded, were found to introduce severe distortion by reason of differences in the transmission efficiency and transmission velocity at different frequencies. Furthermore, large variations in transmission loss resulted from changes in the electrical resistance of cable conductors with temperature, or from changes in the leakage of open-wire conductors. Extensive developments in the field of network theory made it possible to design equalizers with frequency characteristics that compensate accurately for the line distortion. Variations in line loss are automatically counteracted by transmission regulators. Devices known as compandors, in which the amplitude of speech syllables serves to compress the range of speech volumes at the transmitting end and to introduce a corresponding expansion at the receiving end, have proved beneficial in reducing the effect of line noise on both wire and radio circuits.

Another unwanted effect on telephone circuits is the presence of electrical echoes due to irregularities in the line. These, when converted into sound, may disturb both talker and listener. The echoes become more annoying the longer they are delayed, and hence are of greatest concern on long circuits. They are controlled by restricting their occurrence, by reducing the line delay or by applying devices called echo suppressors to prevent their reaching the telephone users.

The vacuum tube provided for the first time the means for precise measurement of these and other transmission effects, and thus made it possible to establish a firm foundation for the transmission art. Vacuum tubes connected as generators of electric oscillations supply the range of frequencies needed for communication measurement. Other vacuum tubes amplify the extremely weak currents involved in telephone transmission to a level at which they can be conveniently measured.

Carrier Systems

It is now rather general practice on long-distance routes to multiply the circuit capacity by the application of carrier telephone systems. These are called carrier systems because of the underlying principle, known as modulation, whereby the voice frequencies modulate a higher frequency current which "carries" the voice currents. A voice wave is composed of undulations with a frequency of occurrence ranging from about 200 to 3,000 per second or, as it is commonly expressed, from 200 to 3,000 cycles per second. In the modulation process these frequencies are transposed to a higher frequency range, *e.g.*, 10,200 to 13,000 cycles per second, for transmission over the line. By using different carrier frequency bands a number of conversations can be sent simultaneously over one transmission path. At the receiving end the carrier frequency bands are separated by electric networks called filters (invented by G. A. Campbell in 1915), and the original voice frequencies recovered by an inverse process known as demodulation. Carrier systems make extensive use of vacuum tubes—as amplifiers, as oscillators for generating carrier frequencies, and sometimes as modulators for shifting bands of frequencies from one range to another.

The art of multiplex carrier telephony grew out of the harmonic telegraph systems associated with the names of Gray, Bell, E. Mercadier and others. The extension of the carrier principle to telephony, together with the use of electrical resonance instead of mechanical resonance for selecting the carrier frequencies, was invented in 1891 by two Frenchmen, Maurice Hutin and Maurice Leblanc. During the period 1908–11, demonstrations of carrier techniques were conducted by Ernst Ruhmer in Germany and Maj. Gen. George O. Squier in the U. S.

Following experiments between Toledo, O., and South Bend, Ind., in 1917, the first commercial application of the carrier principle was made in 1918 on an open-wire line between Baltimore, Md., and Pittsburgh, Pa., giving four additional telephone circuits on a pair of wires. With modern carrier techniques, as many as 16 telephone circuits are derived from a single open-wire pair. Beginning in 1934 in Germany, a system which yielded one extra telephone channel on a lightly loaded cable pair was extensively applied in Europe.

Application of substantial numbers of carrier channels to cables necessitates many more repeaters because of the higher attenuation of the cable pairs, so that minor imperfections in each amplifier become quite serious. The solution to this problem was provided by Harold S. Black when he invented the negative feed-back amplifier in 1927. The complete development of the underlying theory came in subsequent work by Harry Nyquist. Though difficult in theory, the idea itself is quite simple. A part of the amplifier output is fed back to the input in such a way as to give practically distortionless amplification, together with almost complete absence of variation in amplification as a result of power supply variation and tube aging. The improvement thus obtained may be a thousandfold or more.

The negative feedback principle is now applied almost universally to amplifiers used for any purpose. This principle formed the basis for the introduction in 1937, between Toledo and South Bend, of a 12-channel carrier system operating on nonloaded cable pairs. Today carrier systems are quite generally used on long-distance cable routes, yielding circuits with excellent transmission properties for distances up to thousands of miles. Important in this connection has been continued progress in the understanding and control of crosstalk and noise. Cable carrier systems in the U. S. are arranged to derive 12 to 24 telephone circuits from two nonloaded 19-gauge pairs. Similar systems, some of them providing much larger numbers of channels, are used in Europe and elsewhere.

With the aid of a special type of cable conductor, called a coaxial unit or merely a coaxial, carrier techniques have been greatly expanded. A coaxial consists essentially of a copper tube, commonly about the size of a lead pencil, with a wire centrally supported inside. A full-size cable may contain as many as eight such coaxials, plus a number of conventional pairs of wire. By applying amplifiers at close intervals, four to eight miles, a very wide band of frequencies can be transmitted over a single coaxial.

The transmission properties of a coaxial circuit were considered by various 19th-century workers, especially Lord Kelvin and Alexander Russell. But it was a far journey from these studies to a wide-band transmission system suitable for long-distance multichannel telephony and television. The first such coaxial systems were applied in 1936 between New York City and Philadelphia and between Berlin and Leipzig. More highly developed systems are now widely used in both the U. S. and Europe.

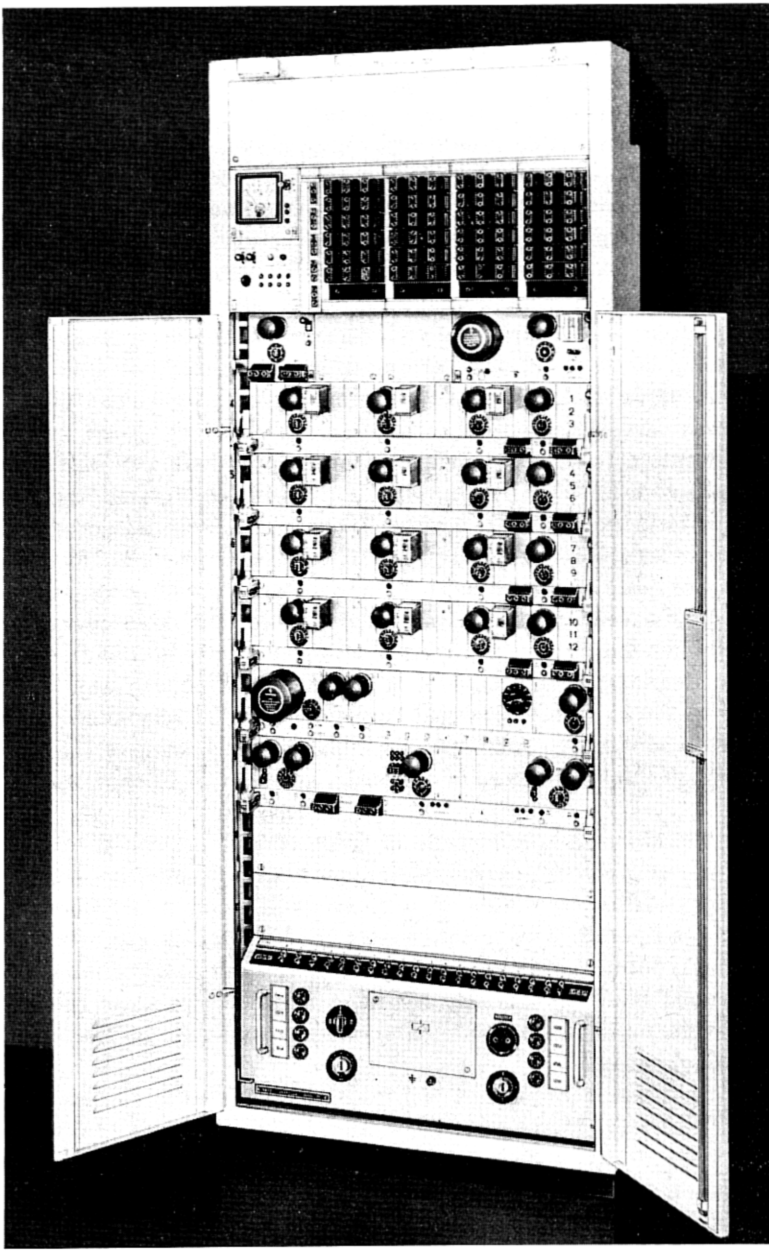


Fig. 9 — Twelve-channel carrier telephone equipment for use on balanced cable pairs. (By courtesy of Siemens & Halske, Ag.)

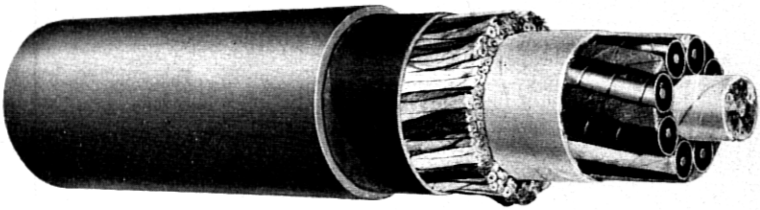


Fig. 10 — Coaxial cable, with eight coaxial units and a number of paper-insulated pairs.

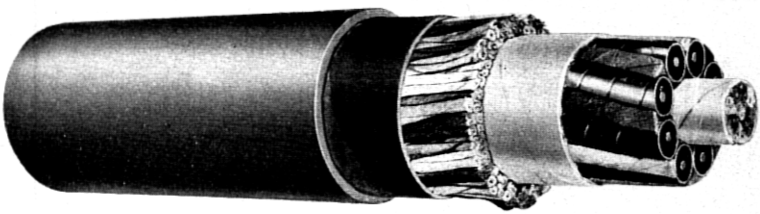
A type of coaxial system introduced between Minneapolis, Minn., and Stevens Point, Wis., in 1939 utilizes a frequency band nearly 3 mc (*i.e.*, 3,000,000 cycles) wide, with two coaxials giving either 600 two-way telephone channels or a television circuit in each direction. Techniques were further augmented in a system, first applied in 1952, which provides a frequency band nearly 8 mc wide, so that two coaxials can provide either (1) 1,800 telephone channels; or (2) 600 telephone channels plus a 4.2-mc television circuit in each direction. Since a long coaxial system may have 1,000 or more repeaters connected in tandem, each one providing a ten-thousandfold amplification, the utmost perfection is necessary in the performance of each repeater.

The minimum distance for which carrier systems prove economical depends on the cost of the terminal apparatus. In recent types of systems the economical distance has been greatly reduced, so that carrier can be used for short-haul toll circuits, interoffice trunks and rural circuits.

Radio

Radio, originally employed for telegraphy, has become an important instrument for telephone purposes. Both the theoretical and the utilitarian aspects of radio transmission are treated elsewhere.

The same basic principle of modulation used in carrier systems is required to shift the telephone signals to the desired radio frequency. There are several different kinds of modulation that may be used in either radio or wire systems. Simplest of these is amplitude modulation, in which the amplitude of a modulating wave (*e.g.*, a speech wave) controls the amplitude of a sine wave carrier. The first complete analysis of amplitude modulation was made by John R. Carson, who showed that in order to convey the intelligence only one of the bands of fre-



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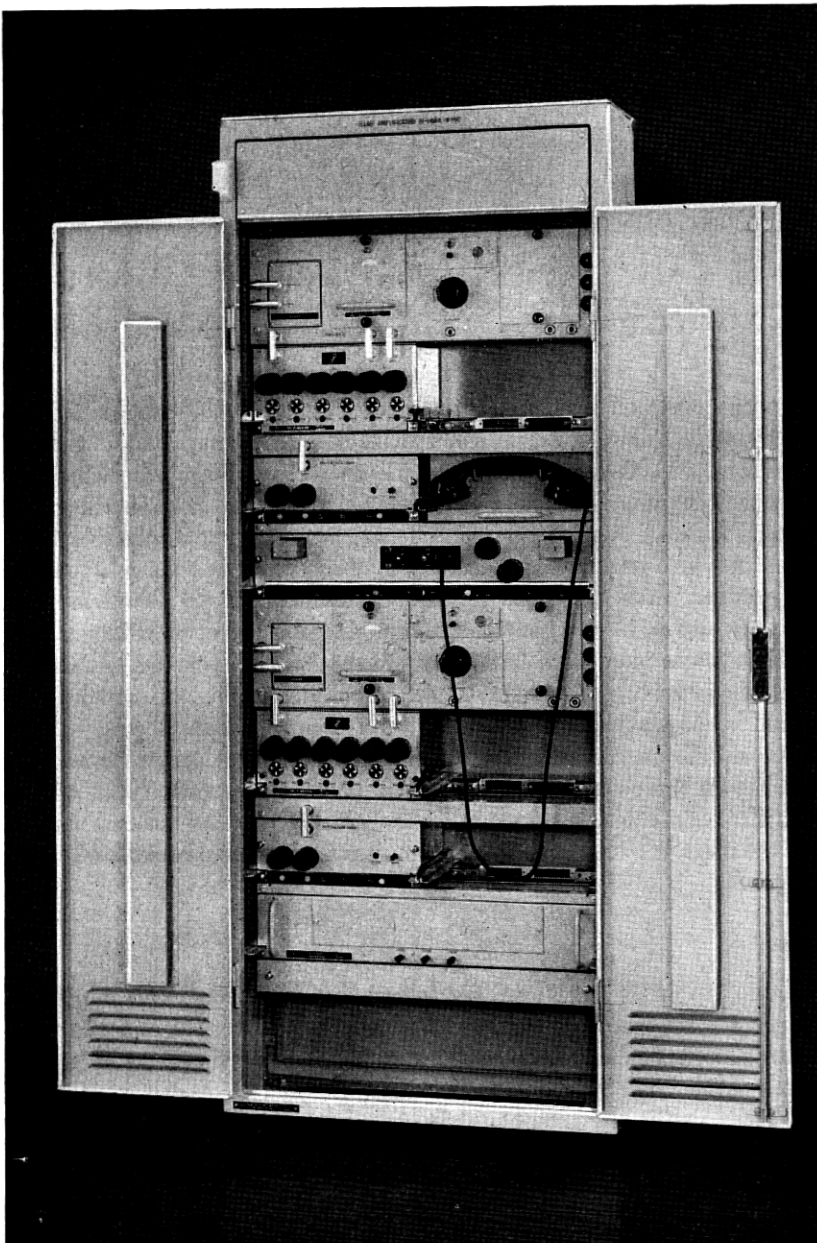

Fig. 11 — Carrier telephone equipment for coaxial cables. (By courtesy of Siemens & Halske, Ag.)

quencies generated in the process need be transmitted. Because of its efficient use of frequency space, Carson's single-sideband method is widely employed.

Another common form is frequency modulation, wherein the instantaneous frequency of a sine wave carrier is varied in proportion to the amplitude of the modulating wave. This method makes it possible by sacrificing frequency space to gain an advantage in the ratio of signal to noise.

Still another form is pulse modulation, in which the carrier consists, not of a sine wave, but of a series of pulses whose amplitude, duration, position or mere presence may be controlled so as to convey the message. In pulse code modulation, originated by A. H. Reeves in 1939, successive quantized samples of the modulating wave produce corresponding code patterns of pulses. This provides, at the expense of band width, low vulnerability to noise and interference and adaptability to repeated regeneration of the signals without distortion. For multi-channel transmission, the pulses corresponding to different channels are interleaved.

The advantages of being able to telephone without a wire connection were obvious from the beginnings of radio. Many early radio experimenters succeeded in transmitting speech over distances of a few miles, notably R. A. Fessenden and De Forest in America and Quirino Majorana, Giuseppe Vanni and V. Poulsen in Europe. Several essentials for practical application were lacking, however; to wit, a practicable generator of continuous high-frequency waves, a means for modulating these waves in accordance with speech and a receiving amplifier for revivifying the waves after enfeeblement in transit. In the main, it was the vacuum tube that provided the solution for all these problems.

In the same year, 1915, when telephone service across the U. S. was begun, intelligible speech was experimentally transmitted by radio from Arlington, Va., to Hawaii and to Paris. In 1927 the first commercial overseas radiotelephone circuit was opened between the U. S. and England. Service from Berlin to Buenos Aires, Arg., was begun in 1928, from England to South America and Australia in 1930, and service between the U. S. and South America, Central America, the Hawaiian Islands, the Philippine Islands, the Netherlands Indies and Japan during the years 1930 to 1934. At the end of 1956 radiotelephone service was available between all principal countries not connected by wire and in addition was used in many instances to supplement wire facilities. There were more than 1,600 calls a day between North America and Europe including radio and submarine cable facilities. Fig. 5 shows the principal overseas telephone connections. Most of the overseas radio-

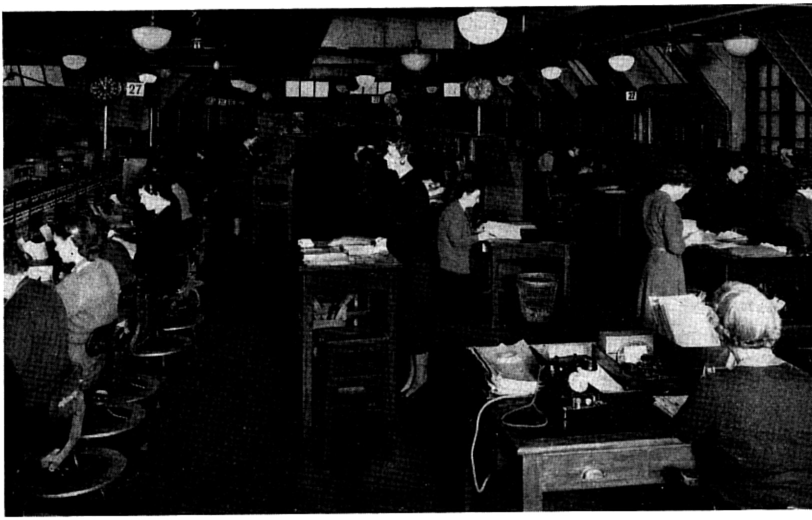

Fig. 12 — Overseas telephone switchboard room, London, England. (By courtesy of Her Majesty's Postmaster General.)

telephone circuits were in the shortwave range from 3 to 30 mc., where long-distance transmission is accomplished by reflecting the waves from the ionosphere. The performance of the radio circuits, although fairly satisfactory, was subject to some difficulty due to atmospheric disturbances.

Radio systems that make use of scattering from the tropospheric layer in the atmosphere to transmit wide frequency bands, capable of handling a number of telephone channels, to distances "beyond the horizon" were introduced in the mid-1950s. A Miami-Havana system went into service in 1957.

Starting with service to the steamship "Leviathan" in 1929, radiotelephone service has been extended to many large ocean-going ships. Thousands of smaller ships in coastal waters, on lakes, in harbors and on rivers are equipped for connection to shore telephone stations by radio. Commercial radiotelephone service between the public telephone system and motor vehicles in cities and on highways began in the U. S. in 1946. In October 1957 there were about 18,000 such mobile stations.

In addition, about 500,000 other vehicles were provided with radiotelephone sets for private services such as those of airlines, police, taxicabs, etc., and there were 16 mobile radio stations for public service on trains. Radio systems were used also for bridging short water gaps and crossing other difficult terrain. Portable radiotelephone equipment

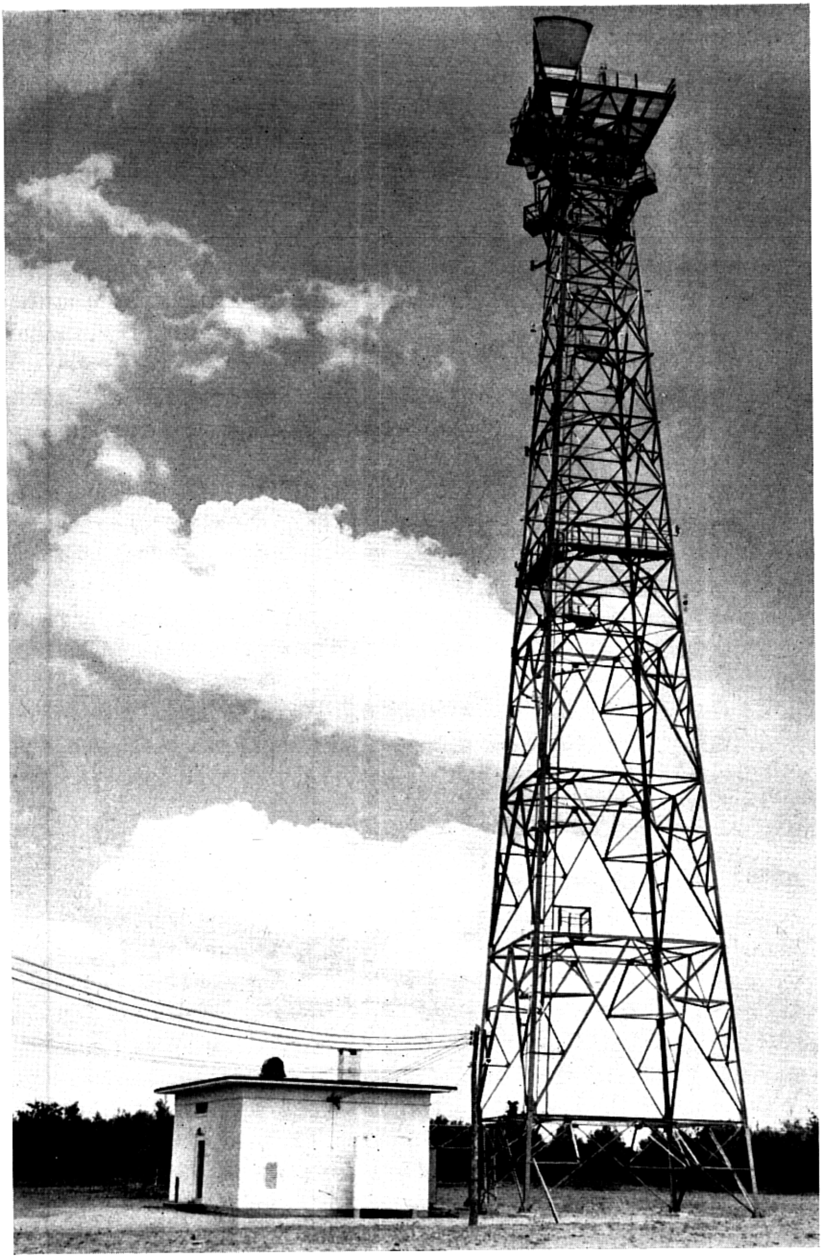

Fig. 13 — Microwave radio relay tower, Dawson, N.S.

was employed in emergencies such as floods or hurricanes to bridge gaps in the regular toll circuits until normal service could be restored. Radio paging systems were available in which a small receiving set carried on the person was used to summon an individual to the nearest telephone in order to place a call to his home or office.

Repeatered radio systems for obtaining substantial numbers of long-distance telephone circuits, as well as broad frequency bands for television transmission, are used in many parts of the world. These commonly transmit radio waves of thousands of megacycles, known as microwaves, over line-of-sight paths. As early as 1934 a microwave radio system developed by A. G. Clavier and others was employed for transmission across the English channel. The large-scale development during World War II of microwave techniques for radar use provided a powerful stimulus in the postwar development of microwave communication systems. A microwave radio-relay (*i.e.*, repeatered) system was placed in service between New York City and Boston in 1947, and one across the United States in 1951. This latter system provides six radio channels in each direction, and each radio channel affords either 600 telephone circuits or a single television circuit.

Concentration of large numbers of circuits on a single route by means of carrier systems, coaxial systems or radio-relay systems yields large economic advantages through sharing common elements of cost including right of way, line conductors, installation, line maintenance, radio towers, power supply, etc. Combining the requirements for both telephony and television on a common route affords further economy.

Submarine Telephony

Submarine cables for transmitting telegraph signals antedated the invention of the telephone. Many years went by, however, before long submarine cables suitable for telephony became practical. As early as 1891 a cable containing four wires was laid under the English channel, between St. Margaret's Bay, Eng., and Sangatte, Fr. During the next five years several cables of similar construction, suitable only for shallow water and relatively short distances, were placed beneath the channel.

When cable is laid in deep water, the high pressure necessitates a different type of cable, the usual construction for deepwater telephone cables consisting of a central conductor surrounded by insulation around which is a return conductor. The first such cables were laid in 1921 between Key West, Fla., and Havana, Cuba, a distance of more than 100 miles. Each of these cables provided a single voice circuit and four telegraph circuits. Two years later the first long submarine cables adapted for carrier telephone transmission were placed across the 40-mile stretch between the California coast and Santa Catalina Island.

For spanning greater distances with the wide frequency band required to accommodate a number of telephone channels, intermediate repeaters are needed. The first submerged telephone repeaters were applied between Anglesey, Wales, and the Isle of Man in 1943 and between Lowestoft, Eng., and Borkum, Ger., in 1946. These repeaters were adapted only for shallow-water operation. Repeaters designed for deep-water use were included in a pair of cables placed in 1950 between Key West and Havana, the two cables giving a total of 24 telephone circuits.

To handle the expanding requirements for transatlantic telephone service, installation of the first transoceanic telephone cable system, between Clarenville, Nfd., and Oban, Scot., with an extension from Newfoundland to Nova Scotia and a radio-relay link to Portland, Me., was begun in 1955 and the system was put in service in 1956. This was a joint project of the American Telephone and Telegraph Company, the British post office and the Canadian Overseas Telecommunication Corporation. The two cables on the main crossing were designed to have 52 submerged repeaters each, spaced at approximately 40-mile intervals, and to provide a total of 36 telephone circuits. The vacuum tube repeaters were designed to operate continuously and flawlessly, with no attention for at least 20 years, at depths up to 2,000 fathoms.

By the end of 1957 similar submarine systems between Port Angeles, Wash., and Ketchikan, Alsk., and between California and Hawaii were in service.

Information Theory

Progress in telephony and allied arts has been greatly furthered by the formulation of a comprehensive theory underlying the communication of information. This theory, variously referred to as information theory or communication theory, has resulted from studies by Claude E. Shannon, Norbert Wiener and others, following earlier work by R. V. L. Hartley. It states in essence that information of the kind contained in messages transmitted over communication systems is measurable; as a consequence, the loss of information caused by unpredictable perturbations (noise) introduced during transmission can be evaluated. The basic unit of measure is a "yes-or-no" choice, which is called a bit (short for binary digit). All information can for communication purposes be expressed as, or encoded into, sequences of on-or-off (*i.e.*, binary) pulses. The development of the basic mathematical theory has made it

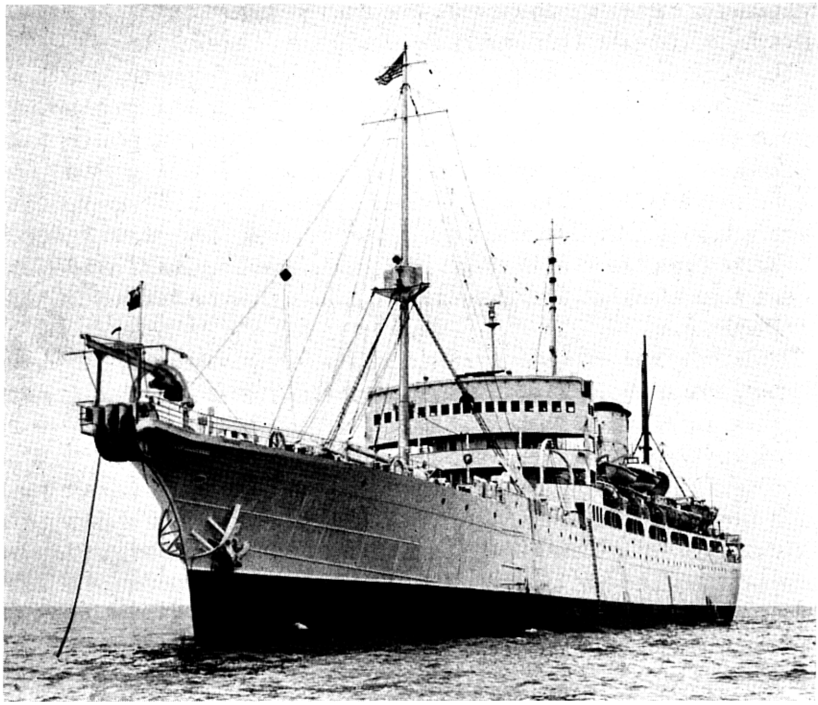

Fig. 14 — H.M.T.S. *Monarch*, owned and operated by the British post office, used in laying the first transatlantic telephone cable.

possible to treat transmission factors such as band width, noise, distortion and the like, and the relations among them, in quantitative terms. This facilitates the comparison of different transmission systems—for example, systems using different forms of modulation, different coding, etc. The theory also establishes absolute upper limits for the rate at which information can be transmitted over systems of different kinds.

Switching

Establishing a connection between any two telephones out of a large group is a complicated process. Even in the simplest situation, where both telephones are served by the same switchboard, it is necessary to: (1) observe that a customer wishes to make a call; (2) connect the operator (or switching mechanism) to his line; (3) determine what telephone he wishes to be connected with; (4) select a speech path between them which is not already in use; (5) determine whether the wanted telephone is idle or busy; (6) if idle, ring the bell, or if busy, inform the calling customer; (7) determine when the call has ended; and (8) restore all equipment to its quiescent state, in readiness for other calls. If the telephones are served by different switchboards, perhaps in widely separated cites, it is also necessary to determine what switchboard serves the wanted telephone and how it may be reached.

From the beginning, the importance of the switching function in telephony was recognized, but the means initially employed were primitive. The first telephone switching arrangement was provided by the Holmes Electric Company at Boston in 1877, by using for telephone connections in the daytime the line wires and plug-and-block connectors employed for a burglar alarm system at night. A commercial telephone switchboard placed in operation at New Haven, Conn., in 1878 served 21 stations on 8 grounded lines. In contrast, a modern central office may serve as many as 100,000 telephones on 50,000 lines.

The New Haven exchange, and other primitive ones, provided a separate switch for each combination of lines that might have to be connected together. For 8 lines this required only 28 switches; but the number of switches increased much more rapidly than the number of customers and quickly became impracticable. With 100 lines, for example, 4,950 switches would have been required. To get around this difficulty, the cord circuit was introduced in 1880. Each line was terminated on the switchboard in a socket (called a jack), and a number of short flexible circuits (called cords) with a plug on each end were also provided. Two lines could thus be interconnected by inserting the two ends of a cord in the appropriate jacks. This was an efficient system as long as the number of calls passing through a switchboard could be handled by a single operator.

Another early invention, which permitted much larger volumes of traffic to be handled efficiently on a manual basis, was the multiple system devised by Leroy B. Firman in 1878. With this, each customer's line is connected to a number of jacks, placed at suitable intervals along the switchboard, so that one is within the reach of every operator.

With the introduction of the multiple system, it became necessary to develop a busy test to determine whether or not a line with which connection was desired was already in use through a connection made at some other part of the switchboard. In a manual switchboard the operator performs this test by touching the tip of a connecting plug to a conducting sleeve forming part of the jack of the desired line. If the line is busy, a click is heard in the operator's receiver.

In 1895 the magnetically operated drop signals which informed the operator of a customer's desire for service were first replaced by incandescent lamps. These were more reliable and smaller than the drop signals, and permitted a much more compact arrangement of the subscribers' jacks.

Since then, there has been continuous improvement to adapt manual switchboards to the growing volume and complexity of telephone traffic and to modern standards of workers' comfort and of customers' convenience. There have also been improvements in the associated circuits. But the design of all subsequent manual switchboards has been based upon the plug-ended cord, the multiple, the busy test and lamp signals.

The idea of fully automatic switching also appeared quite early. In fact the first patent for an automatic switching system was issued to Daniel Connolly, T. A. Connolly and T. J. McTighe in 1879, only two years after the first primitive switchboard in Boston. This system never achieved commercial success. In 1889 Almon B. Strowger invented an automatic system which was installed at La Porte, Ind., in 1892, the first commercial automatic exchange in the world. The system was subsequently developed by Alexander E. Keith and other engineers of the Automatic Electric Company into a form which is still extensively used throughout the world under the names step-by-step or Strowger system. In this system the switching mechanisms are operated directly by pulses generated at a customer's instrument. Originally a customer operated a push button to produce the switching pulses, but this and other types of calling devices gradually gave way to the dial mechanism now in general use. This was invented in 1896 by A. E. Keith, C. J. Erickson and John Erickson of the Automatic Electric Company.

The basic mechanism around which the Strowger system is built is the Strowger switch, which is sometimes called a connector and sometimes a selector according to the use to which it is put. In complete form this consists essentially of two parts: a ten-by-ten array of terminals (the bank) arranged in a cylindrical arc; and a movable switch (the brush) which is translated along the axis of the cylinder by one ratchet mechanism and rotated about it by another, so that it can be brought to the position of any one of the 100 terminals. Each ratchet mechanism is driven by an electromagnet, which can respond to the pulses produced by a telephone dial.

Many other switching systems have been invented, notably in the United States, Germany and Sweden, and a number of them have been put into successful commercial operation. Some of these have operated on the step-by-step principle but have used different types of apparatus. Others have operated on the principle of common control, in which pulses are stored for a short time in a device which then controls the switches either directly or through some intermediate mechanism.

The distinguishing feature of such systems is that the common-control

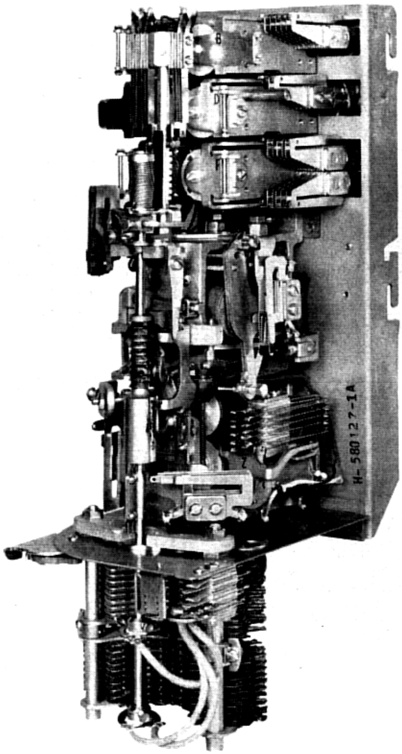

Fig. 15 — Step-by-step selector (United States). (By courtesy of Automatic Electric Co.)

mechanisms (known as registers, senders, translators, directors, markers, etc.) are not assigned to the customer for the duration of his call, but are used only as long as they are needed and are then free to serve other customers. Thus each serves many calls per hour, and few are required; it is therefore practicable to provide complicated devices which can perform a variety of useful functions, but which would be too expensive to assign for the duration of the call. Systems using common control have great flexibility and efficiency in the use of trunk groups, and are especially advantageous for large exchanges and for automatic routing of long-distance calls.

The earliest common-control systems were developed by the Western Electric Company, primarily to meet the needs of large metropolitan centers. In a program beginning in 1906, two systems were developed

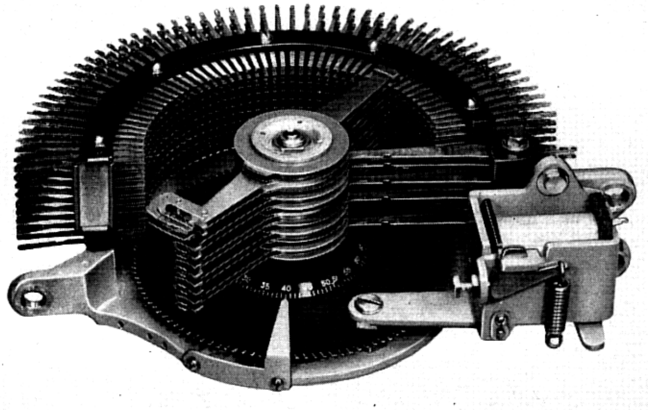

Fig. 16 — A rotary selector (Belgium). (By courtesy of International Telephone and Telegraph Co.)

alongside one another, and both proved to be successful. One, called the rotary system, was first put into commercial service in England in 1914. The other, called the panel system, went into commercial use at Newark, N. J., in January of the following year. Common-control principles were also applied to the step-by-step switch by the Automatic Electric Company, and the resulting system was adopted by the British post office in 1922 for use in London. The most recent common-control systems have been crossbar systems, of which several commercial types have been developed by the Bell System in the United States, by the Swedish Telecommunication admistration and the L. M. Ericsson Company in Sweden and by subsidiary companies of the International Telephone and Telegraph Company in Belgium and Germany.

The most important concepts in the evolution of the modern types of crossbar exchange were probably translation, the sender, the marker, the crossbar switch and the principle of call-back operation.

Translation, invented by E. C. Molina of the American Telephone and Telegraph Company in 1906, makes it possible to convert incoming dial pulses from decimal to nondecimal form and thus affords flexibility and efficiency in the use of trunk groups.

The sender, first used in the rotary system, is essentially an automatic mechanism which generates new dialing signals, either in the code given by the translator or in other appropriate codes.

The basic function of the marker is to make a preliminary test of several alternative paths to a wanted destination through an array of switches, before any of the switches is closed, so as to avoid the possibility of encountering a busy switch after part of the switching operation has been performed. It was invented by N. G. Palmgren and G. A. Betulander of Sweden in 1912, and was first used commercially in a system manufactured by the Relay Automatic Company of England from 1915 to 1920. As used in crossbar systems of the Bell System, it has been developed into a complex assemblage of electromagnetic relays which serves as the basic control element for the entire switching operation. Among other things, it tests the circuits before connections are established; it seeks out alternate paths when needed; and it reports trouble conditions which may be encountered in its preliminary tests.

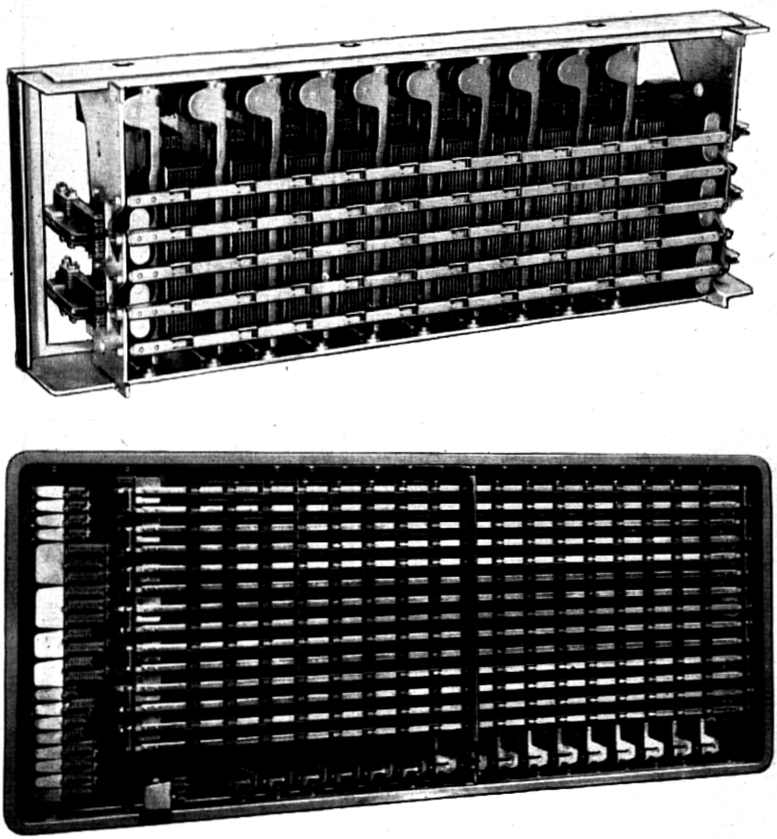

Fig. 17 — *Top:* Crossbar switch, present date design by the Swedish Telecommunications Administration. (By courtesy of Swedish Board of Telecommunications.) *Bottom:* "Pentaconta" crossbar (France). (By courtesy of International Telephone and Telegraph Co.)

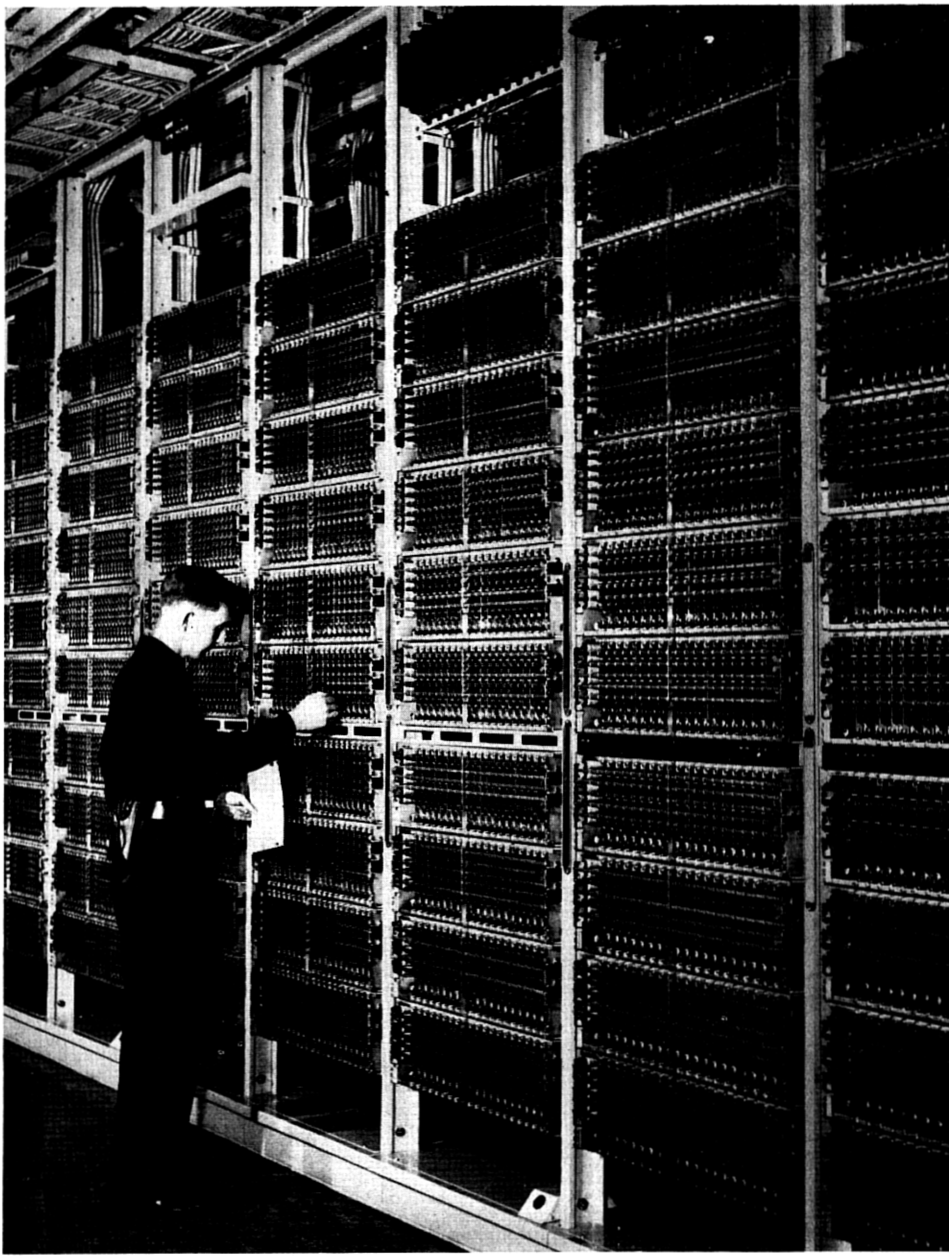

Fig. 18 — Part of a crossbar switching system.

Since it can examine a large number of trunk circuits practically simultaneously, it uses them with great efficiency.

The crossbar switch is essentially a multiple relay structure affording fast operation and reliable contacts of precious metal. Unlike other switches mentioned above, the moving parts have little inertia and move through small distances. It was first conceived in America by Homer J. Roberts of Automatic Electric Company in 1901, and later patented in separate forms by John G. Roberts and John N. Reynolds, both of Western Electric Company. The first satisfactory mechanical design, worked out by Palmgren and Betulander in Sweden in 1919, was used by the Swedish telephone authorities in a commercial exchange in 1926. Aside from a small-scale trial installation in Stockholm in 1919, which was subsequently abandoned, this was the first public use of the crossbar switch. The system in which it was used, however, and all other crossbar exchanges in Sweden until very recent years, operated on step-by-step principles. Most of the crossbar switches used in America and other countries today follow rather closely the Swedish design.

Call back is a principle of operation, invented by Edson L. Erwin in 1938, which has been effectively used in crossbar systems. When a customer originates a call, the register stores not only the wanted number, but also the identity of the calling telephone which is determined automatically. The connection with the calling subscriber is then disconnected, and an entirely new connection established, from a favourable point within the exchange, to both the calling and wanted telephones.

As automatic switching systems were improved, their application was extended until, in the mid-1950s, 77 per cent of the world's telephones were automatic, as compared with 15 per cent only three decades earlier. This metamorphosis occurred not only because automatic operation is faster, more accurate and more economical than manual service, but more basically because in many areas the enormous number of operators necessary to support the rapid telephone growth would have far exceeded the possible supply.

In America the crossbar system, designed originally for metropolitan areas, presented so many advantages as compared with earlier automatic systems that its basic principles were soon applied in other fields. Crossbar tandem equipment, for example, is the modern version of the tandem principle developed originally for manual systems. Through the tandem scheme, traffic between offices on opposite sides of a large metropolitan area is handled through one or more intermediate (tandem) offices which act as clearinghouses for these relatively small amounts of traffic, handling them more efficiently than if direct paths were provided and thus reducing the number of trunk circuits required.

Another type of crossbar system is specially adapted to the automatic switching of long-distance circuits. With this, connections are made on a two-path or four-wire basis, a separate path being used for each direction of transmission so as to obtain superior transmission performance on connections comprising a number of circuit links in tandem.

The first crossbar switching system in the long-distance field, introduced in Philadelphia in 1943, enabled operators but not customers to dial long-distance calls. This advance was followed by another which permitted direct dialing by customers without the aid of an operator. The switching mechanism selects the route to the distant telephone. Should it find all direct circuits busy, it explores in succession as many as five alternate routes, and establishes the connection along the least circuitous one which is available. All this is done automatically. Necessary information regarding direct and alternate routes to the destination is permanently available in a translator, which supplies it to the control circuits as required.

Arrangements for customer dialing of at least some intercity calls were provided in all the principal countries of the world by the mid-1950s. In North America a complete program was worked out for eventually handling substantially all calls in this way. The initial installation of equipment to permit nation-wide dialing by customers was placed in service at Englewood, N. J., in 1951. With this equipment, customers were able to dial directly about 11,000,000 other customers in selected areas as far away as San Francisco. They dial a three-digit area code followed by the digits of the directory listing of the called number. At the end of 1956 this type of service had been extended to 253 originating locations reaching about 30,000,000 customers.

Closely related to automatic switching is the automatic recording of data for preparing a customer's bill. The simplest means for this purpose, used in either manual or automatic offices, is an electromechanical counter, known as a message register, which records the number of calls made by a customer. In a more elaborate arrangement, referred to as multi-unit registration, the register can be operated more than once for a single call, the number of operations depending on the distance and duration of the call. Each customer is billed on a bulk basis for all of the "message units" totaled on his register. This plan is widely used in America, and almost universally elsewhere.

Another method of charging is "automatic ticketing," first introduced in Belgium. With this method, automatic equipment prints for each call a ticket similar to one that might be prepared by an operator.

In America, where distances are great and the tariff structure complicated, a highly versatile type of message registration system, called automatic message accounting (usually abbreviated to AMA), was developed by the mid-1950s. In this system the information needed for billing calls is recorded in the form of coded holes in paper tape. Automatic processing of the tapes in an accounting center yields bills with any desired amount of detail. The AMA system is extensively used in association with direct distance dialing.

A big step in the improvement of telephone service in outlying areas resulted from automatizing the telephone switching in very small communities. Community dial offices, either of the step-by-step or all-relay type, were provided in many localities. These function with no attendance except for occasional maintenance visits.

Another phase of telephone switching is found in switchboards, known as private branch exchanges, which are located on the customer's

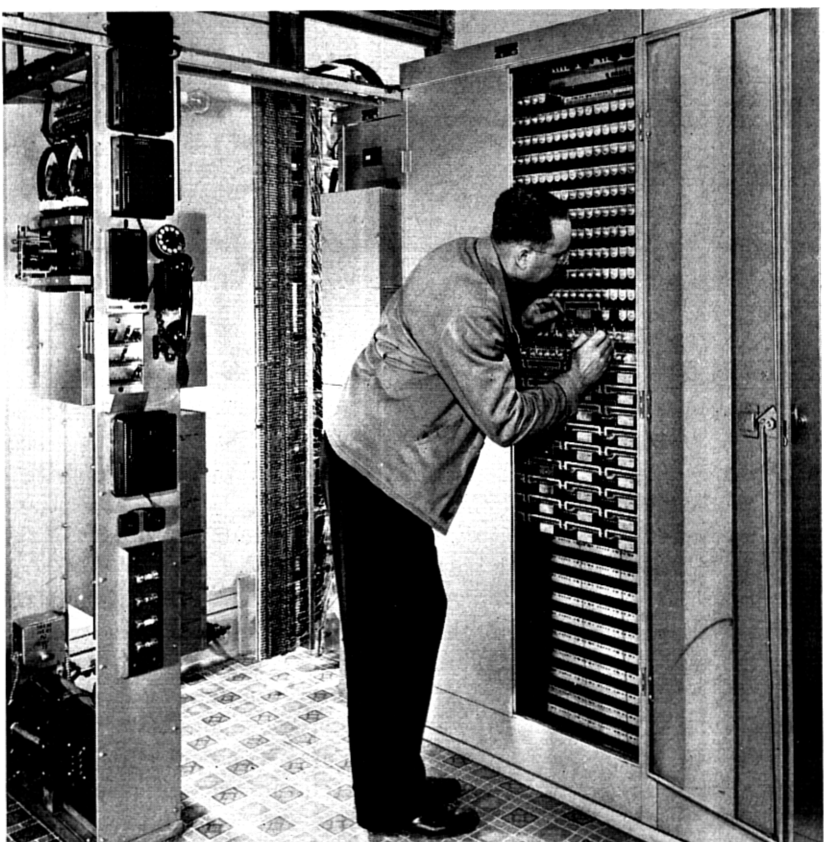

Fig. 19 — All-relay community dial office for telephone service in outlying areas. (By courtesy of North Electric Co.)

Fig. 20 — Private branch exchange switchboard, capable of handling both internal and central office calls. Used in business offices.

premises. The private branch exchange (abbreviated PBX) serves both for interconnecting the station sets of the customer's establishment and for connection over trunk lines to the central office. The smaller PBX's can be placed on a desk and operated by a person who may perform other duties as well. Large PBX's resemble central office switchboards and may be of either the manual or automatic type.

By the mid-1950s exploratory developments were under way in the principal communications laboratories of many countries with the ultimate objective of replacing electromechanical switching systems by electronic ones. A small beginning had already been made in some units that are partly electronic and partly electromechanical. Among these may be mentioned the line concentrator of the Bell System, an unattended switching unit which permits a small number of lines to be shared by a substantially larger number of customers without the disadvantages of party-line service; and the mechanoelectric system developed by the International Telephone and Telegraph Company in Belgium and first installed at Ski, Nor., in 1954.

The Bell System announced also that a fully electronic system was under development, and was expected to be placed in commercial service in Morris, Ill.

Associated Services

Much of the plant required for telephone service is well adapted to the provision of other types of communication service, so that economies can usually be effected by designing the plant to handle the combined requirements of different services. The earliest of such associations was with the telegraph. Direct current telegraph channels superposed on the telephone wires were leased to private customers and to the companies furnishing message telegraph service, and were employed also for telephone line maintenance. The introduction of carrier transmission methods made it possible to derive as many as 18 telegraph channels from one telephone circuit. Such channels serve both for teletypewriter exchange service, which is a switched service analogous to telephone service, and also for private-line teletypewriter service.

Satisfactory picture transmission requires a frequency band of about the same width as that for telephone conversation. Special networks are provided for picture service, and occasional use is made of regular telephone circuits for this purpose. Telephone circuits are employed also to render facsimile and other services. High-speed transmission of information in the form of pulses is being increasingly applied for both commercial and military purposes, one common application being to supply data to electronic computers.

Generally speaking, the chain networks used for the radio broadcasting of either sound or television programs are provided in conjunction with the telephone plant. For good quality of music reproduction, a frequency band somewhat wider than that adequate for speech is required. Television broadcasting necessitates a very wide frequency band, equivalent to that required for about 1,000 telephone circuits.

Television circuits are derived, commonly in association with large numbers of telephone channels, from coaxial or microwave systems. Wire broadcasting systems, in which sound programs are conveyed by wire directly to the customers' premises, are in limited use.

TRENDS

Technical trends likely to be present in telephony over the years to come were foreshadowed by various developments in progress by the mid-1950s. Foremost in the area of new art was the transistor, invented by W. H. Brattain and John Bardeen in 1948. This is a three-electrode amplifying device employing a semiconductor such as germanium or silicon. A preferred form, known as the junction transistor, was invented later by William Shockley. The transistor can perform many of the functions previously assigned to vacuum tubes, but is far more efficient because it requires no power to heat a cathode. Additionally, it operates with much lower electrode voltages and is much smaller than a vacuum tube (Fig. 21). Because of the transistor's low power dissipation and low voltage requirements, other electronic components associated with it can be miniaturized. The over-all result is that the size, weight and power consumption of apparatus employing transistors can usually be reduced to a small fraction of that for equivalent apparatus using vacuum tubes.

Transistors therefore held prospect of finding large and varied applications in almost every field of communication, and particularly in telephony and associated services, including not only areas where vacuum tubes were previously used, but many new areas as well. Thus transistors promised economies through more extensive use of amplification and carrier techniques in the local telephone plant.

All of the automatic switching systems described have been built around the electromagnetic relay and other electromagnetically operated devices. The relay dates back to the early part of the 19th century, and in a form much cruder than the present was the basis for the development of telegraphy. It employs magnetic attraction produced by an electric current to move an armature and thus open or close electric contacts so as to perform switching or other operations. Devices of this kind require a minimum of several thousandths of a second to operate. In contrast, electronic devices such as the transistor may be used to perform switching operations with a speed of the order of a few millionths of a second. Not only so, but a more complex operation involving choices based on conditions existing at the instant can be performed in a similar time interval.

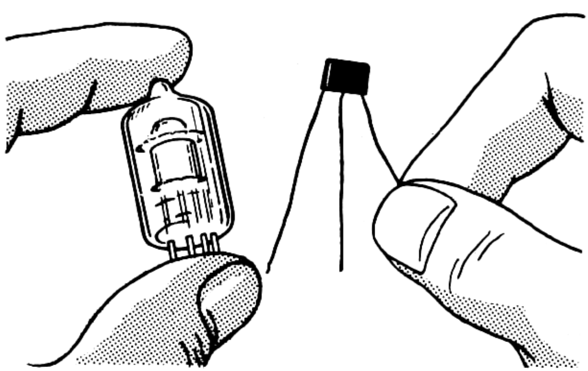

Fig. 21 — Comparative sizes of vacuum tube (left) and transistor.

This means that no longer must a large complement of apparatus be set aside to serve a customer during the entire period of his call, or even a large part of it. The extremely high speed was expected to afford substantial economies in new switching systems through centralizing of functions and time sharing of the apparatus used for establishing connections. The common apparatus would serve a large number of customers in such rapid succession that each one receives the equivalent of continuous and exclusive service. Reduction of space and power requirements would yield further economy. The same speed advantage could be realized with vacuum tube electronics, but with attendant disadvantages in size, power consumption, life and reliability. Altogether, the new art of solid state electronics provided the basis for a revolution in both switching and transmission technology.

The introduction of intercontinental submarine cables, not only of the type being installed in the mid-1950s but also with new apparatus capable of handling larger numbers of telephone channels, was expected to be of particular importance to world communication. Television transmission across ocean barriers was likewise a possibility. Research under way on the use of hollow wave-guide conductors as transmission lines held in store new long-distance systems that would transmit extremely wide bands of frequencies, of the order of thousands of megacycles, able to provide a great multiplicity of communication channels.

As to telephone service in general, there were, in the mid-1950s, no indications of saturation in demand, even in highly developed areas. Substantial further growth in number of telephones and their utilization was therefore in prospect. Large expansion in the services associated with telephony could likewise be envisioned. More fundamentally, it was anticipated that improved communications would contribute greatly to the development of culture and understanding among peoples.

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