of their food from stations conveniently placed and regularly supplied with wheat. For example, in a certain restaurant extensive damage was being done until, after surplus baiting was started, the rats confined their attention almost entirely to the wheat.

Wild rats' consumption of prebait (per kgm. body weight) is being compared in different environments and with the amount eaten in captivity. A number of rats are trapped alive from a prebaited population and the subsequent drop in take is attributed to their removal. The rats are weighed, sexed and fed for a few days in a large outdoor cage. Experiments in progress may make it possible to convert the present relative census method into one giving the approximate number of rats.

*Disturbance.* The provision of unlimited food may sometimes alter existing conditions, and immigrants will be attracted if the baiting points are not, as they should be, spaced out to cover the whole colony at once. A fluctuating food supply is frequent among rat colonies and short periods of prebaiting seem unlikely to produce results that will invalidate the census or disturb the population. If token baiting is carried out during the build-up period, a surplus need only be provided for two or three days afterwards.

*Specificity of the method.* Animals other than rats and mice (the latter, when present at all, eat relatively little) can be kept from the bait by providing cover such as a large box with a 3-in. diameter hole; but it is most convenient to use small containers of a standard design developed by the Bureau.

*Summary.* A method of relative census for brown rats consists of measuring the feeding capacity of the population. It is simple to carry out, applicable in a wide variety of habitats and involves a minimum of interference with the rats. No other suitable technique is known that does not involve killing the rats. The method should be applicable to other populations which consist of only one species of small mammal.


[1] Dice, L. R., *J. Wildlife Management*, **5**, 398 (1941).

[2] Williams, C. L., *Publ. Hlth. Rep. Wash.*, **47**, 765 (1932).

[3] Peirce, E. R., *Med. Off.*, **43**, 222 (1930).

[4] Dopmeyer, A. L., *Publ. Hlth. Rep. Wash.*, **51**, 1533 (1936).

[5] Pemberton, C. E., Bull. Hawaii. Sug. Ass. Ent. Ser., No. 17, 1–46 (1925).

[6] Doty, R. E., *Hawaii. Plant. Rec.*, **42**, 39 (1938).


# FUTURE OF TRANSOCEANIC TELEPHONY*

TELEPHONY was born from telegraphy by an expansion of the band of frequencies employed in the electrical transmission of intelligence. More recently, further expansion has produced improvement of quality of transmitted speech and an increase of the number of simultaneously transmitted conversations. To-day, speech can be transmitted overland perfectly for any distance and with hundreds of conversations at once over a single coaxial line.

Telegraphy takes a certain band-width measured in cycles per second for a particular speed of signalling measured in words per minute. A telegraph machine printing 60 words a minute needs about 100 cycles and intelligible telephone communication requires about 1,000 cycles. 3,000 cycles for commercial telephony is now a reasonable engineering standard although it does not provide for perfect speech transmission. Speech frequencies cover about 8,000 cycles, though frequencies above 4,000 contribute little to intelligibility or quality. The range of the normal human ear is about 15,000 cycles and perfect transmission of music requires that band-width. Little is lost, however, if the music is limited to 8,000 cycles. Television requires from 20,000 cycles for a recognizable human face to 20 millions or more for vision as well defined as in standard cinema practice, but in present commercial practice the band-width is limited to about 3 million cycles.

The available frequency range of a transmission line of given band-width can be allocated to telegraphy, telephony or television at will. Twenty printing telegraph channels with adequate separation cost in frequencies about as much as one ordinary telephone channel, but for a television channel the equivalent, in frequencies, is 1,000 telephone or 20,000 printing telegraph channels.

A major advance in trans-Atlantic cable telegraphy ensued with the introduction of the permalloy-loaded cable in 1924, having a band-width many times that of corresponding non-loaded cables. The fastest loaded trans-Atlantic cable has an effective frequency band of more than 100 c./s. and can carry four times as much traffic as a non-loaded cable of the same size and length. Development of permalloy loading led to the manufacture of a 20-mile section of this type of cable in 1930, and while all the measurements in the laboratory, at sea, and from shore confirmed the technical soundness of the proposal to install such a cable, the project was postponed temporarily because of general business depression and later, indefinitely, because of the improvements in trans-Atlantic radio communication.

In the development of radio for transoceanic communication, only two isolated ranges of the band spectrum are utilized, each of which is comparatively narrow. The low-frequency range is a band some tens of kilocycles wide with a top of about 100 kc. In the 1920's the band of frequencies useful for long distances was widened several hundredfold by the discovery of short-wave transmission at frequencies in the range of 3–30 mc. This put transoceanic radio communication on its present world-wide basis. Short waves contributed also to the demand for service, since the apparatus required for short-wave circuits cost less than that for long waves.

The trans-Atlantic telephone started in the relatively cramped long-wave band and then moved into the freer region of the short-wave range. Speech was first sent across the oceans from Arlington, Va., to Paris and to Honolulu in 1915. For its accomplishment the first high-power vacuum tubes and the first master-oscillator, power-amplifier tube transmitter were evolved. In the long-wave range and for trans-Atlantic distances, radio is seriously limited in respect of the high noise-level, particularly in summer, due to thunderstorms in northern latitudes, and of the weakness of the received signals during the sunset and sunrise periods. The development of the water-cooled, high-power vacuum tube made possible high-power amplifiers to deliver tens of kilowatts needed to lift the signal higher above the level of atmospheric noise. The influence of static was

* Substance of the thirty-third Kelvin Lecture delivered before the Institution of Electrical Engineers by Dr. Oliver E. Buckley, of the Bell Telephone Laboratories, on April 23.

further reduced by the use of directive receiving antennas. Additional improvement was provided by the technique of single-sideband transmission first used on wires. These and other developments assured fairly reliable telephone connexions and in 1927 public service was opened jointly by the General Post Office and the American Telephone and Telegraph Co. The carrier frequency was 60 kc./s., corresponding to a wave-length of 5,000 m.

The opening of the first trans-Atlantic short-wave telephone circuit in 1928 followed close on the long-wave circuit, and was followed in turn by additional short-wave circuits in 1929. Opportunities for greatly improving short-wave transmission then appeared so that the project of the second long-wave circuit was deferred and, later, postponed indefinitely. More recently, experiments have demonstrated the feasibility of transmitting two channels at different frequencies using the same transmitting equipment.

Short-wave radio gives less attenuation, lower noise and a wider frequency band in which to operate compared to long waves for transoceanic service. For a radio-telephone connexion between the United States and England the cost of short waves for an approximately comparable quality of service is about one half that of long waves. The wider band provides an opportunity for the service to expand, and it is hundreds of times wider than the long-wave band. These advantages have been reflected in the rapid growth of short-wave transoceanic telephony; at the beginning of 1939 there were in service throughout the world about 170 important long-distance short-wave telephone circuits, of which five were in regular use between the United States and Europe. There has grown up also a host of short-wave broadcasting channels, the better co-ordination of which had yet to be worked out.

Short-wave transmission, however, is susceptible to periodical interruption, particularly around the maxima of the eleven-year sunspot cycle. Short waves are also affected adversely by various types of signal distortion as the received signal is usually made up of several components which have travelled over different paths. Sometimes these paths all lie along the same great circle but involve different numbers of reflexions between the earth and the Heaviside layer. Sometimes signal components arrive over other than the great-circle path. Occasionally components travel along the longer of the two great-circle paths between the transmitter and receiver, or even clear around the world, producing 'round-the-world echo'. Interference between waves arriving over different paths results at times in 'general fading' caused by variations in the level of the whole band and at other times in 'selective fading' in which portions of the speech band are affected differently.

Single-sideband transmission has, however, helped in eliminating the periodical fading out of the carrier signal which particularly gives rise to a harsh, grating received speech. The multiple-unit steerable antenna (MUSA) recently developed in Bell Telephone Laboratories reduces selective fading by combining signals arriving over different paths or by eliminating all signals except those arriving over one path. Additional antenna directivity makes possible operation in periods of reduced signal strength, though it does not eliminate circuit interruptions at times of very severe disturbance. Single-sideband transmission and the 'MUSA' are now in regular use on the New York–London telephone circuits.

The most significant recent development in land-line telephony is that of broad-band transmission by carrier methods over open wires, cables and coaxial conductors of a considerable group of telephone bands on closely spaced channels. Over open-wire lines and over pairs in lead-covered cables, 12 telephone bands spaced at 4,000-cycle intervals are commonly transmitted in a group occupying a total band-width of 48,000 cycles. With coaxial conductors the band has been increased to 2 million cycles, giving frequency space for some 500 telephone channels, and it may be expanded still further.

The application of broad-band methods to transoceanic radio telephony are likely. Commercial success has already been achieved with small numbers of channels in the Holland–East Indies and the United States–England single-sideband systems. By applying the principles of negative feedback, Bell Laboratories engineers have developed a short-wave transmitting amplifier of 200 kw. capable of handling twelve or more closely spaced telephone channels.

When the sun is over the mid-Atlantic in summer there is available a useful band about 4 mc. wide, in the 14–18 mc. range. These short waves cannot be counted upon, however, to be duplicated very often for simultaneous use at different locations throughout the world. The available 4 mc. band must be divided therefore to meet a large number of requirements, and public service telephony across the Atlantic deserves something like a tenth of the total facilities in this band. This would mean an allocation of 400 kc. or 100 one-way telephone channels, yielding 50 or more two-way circuits realizable under the natural limitations of the medium and the other requirements placed upon it.

We can anticipate with confidence a great growth of trans-Atlantic telephone traffic, but in proportion as the demands for service grow and we come closer to the realization of the ultimate physical possibilities, the more serious becomes the threat of interruption to this service by magnetic storms.

These conclusions lead to reconsideration of the trans-Atlantic telephone cable as an auxiliary to short-wave systems. A single-channel cable would be of little value in supplementing a radio-telephone service of so many channels as there may be in the future. Moreover, the cable must also be capable of carrying a considerable group of telephone channels, and much progress has been made in that direction.

A multi-channel telephone cable to cross the ocean would have to be provided with intermediate repeaters on the ocean bottom, the repeater housing being incorporated within the cable structure. A small diameter housing incorporated as a part of the cable was therefore developed, the whole structure being so flexible that it could be bent around a cable drum.

The repeater housing comprised first a succession of pressure-resisting steel rings each having a diameter of about $1\frac{1}{2}$ in. and a width of $\frac{3}{4}$ in. Over these is slid a succession of thinner steel rings of the same width but overlapping the joints of the inner rings, the whole forming an articulated cylinder about 7 ft. long. An annealed copper tube with water-tight end seals is placed over this cylinder. Within the housing the repeater elements are separately contained in plastic cylinders about 6 in. long, loosely fitting inside the inner steel rings. Connexions between these units are made with flexible conductors. D.C. constant-current power must be fed to the repeater over the cable, and an operating potential of 2,000 volts to earth, oppositely poled at the ends of the cable, was assumed. The repeater elements must rarely require attention and twenty years without replacement of parts was assumed to be reasonable. The problem of life and maintenance is principally one of a rugged long-lived vacuum tube. Ordinary vacuum tubes have limited service life on account of evaporation of material from thermionic cathodes. By making the level of transmitted signals relatively low, the space current may be kept very small and by making the cathode surface relatively large, this small current can be obtained at a temperature so low that the cathodes of the tubes may be expected to last for a very long time.

The number and spacing of repeaters depends on the length and design of the cable. For a cable 2,000 miles long to connect Newfoundland and Great Britain, forty-seven repeaters spaced 42 miles apart would provide for the transmission of a band 48,000 cycles wide.

The repeater is a one-way device and to provide two-way conversations two cables have been assumed, one directed eastward and the other westward. Assigning 4,000 cycles per channel, there would be room for twelve telephone circuits and as many as twenty-four fairly satisfactory 2,000-cycle channels could be provided.

As to the costs of such a cable for broad-band wire telephony to England via Newfoundland, even at somewhat higher annual charges than usual the total cost per telephone circuit for two cables with associated equipment would be comparable with that of prospective short-wave radio systems.

Short-wave radio links have a great advantage in affording direct connexion between points on the globe far apart, and the tendency has been to establish short-wave connexions directly between large centres rather than through extensive land-line links. The introduction of broad-band methods for transoceanic radio telephony will tend to favour centralizing radio traffic at a smaller number of more important terminals, but it is scarcely to be expected that all transoceanic radio traffic will thus be concentrated.

The world-wide transoceanic network of the future may well envisage a net comprising a large number of light linkages plus a small number of heavy linkages over the most important routes. The light linkages will represent direct short-wave single-channel or twin-channel connexions using relatively small power. The heavy linkages will comprise highly developed powerful broad-band short-wave radio systems making full use of frequency and directional diversity supplemented by broad-band submarine cables and in a few cases by long-wave radio as well.

One possible way to estimate the future for trans-Atlantic telephony is to compare the flow of telegraph traffic, say, between London and New York, with that between New York and San Francisco. Difference in community of interest is compensated to some degree by the difference in size of London and San Francisco.

This comparison may be made on the two bases of telegraph traffic, using the total number of words transmitted in a single year as the measure, and of the number of public service telegraph messages, excluding Press service, leased-wire service and code and cipher messages. In each case the estimate is based on terminating messages only. Data for the year 1937 are available and this particular year represents something between the 1929 peak and the trough of the succeeding depression.

On the first basis of comparison the total number of telegraph words transmitted over the two routes in 1937 was approximately the same. On the second basis the number of telegraph messages was about seven times as great between New York and London as between New York and San Francisco. The wide discrepancy between the two comparisons is doubtless accounted for partly by rates and partly by the character of business and social intercourse. Of the two, the second, which is based on plain-word public-service messages, appears more significant in relation to potential demand for telephone service, since public message telegraphy, as a somewhat closer approximation to the informal exchange of ideas by telephone, may be a better index of telephone demand. The potential demand for telephone connexion between New York and London is thus probably somewhere between one and seven times that between New York and San Francisco. Actually, in 1937 the telephone traffic between New York and San Francisco was about three times that between New York and London so that not more than a third, and possibly not more than a twentieth, of the potential telephone demand has been realized.

Assuming that the same ratio of potential to realized demand exists for all European–North American connexions as for the New York–London connexion, it may be estimated that 15–100 circuits will be needed across the North Atlantic depending on costs, but a demand for forty or more telephone circuits may justifiably be predicted in the reasonably near future.

To provide this increase in number of circuits, and to approach land-line standards of reliability and quality of service, all three systems—short-wave, long-wave and repeater cable—will need to be used. The bulk of the trans-Atlantic business will be handled on the short wave, but such an important service would have to maintain a higher standard of reliability than short-wave circuits alone can provide. A cable between America and Britain would provide this reliability, and it would set a high standard of transmission performance in competition with short waves.

It may not be necessary to wait until the growth of trans-Atlantic telephone business provides enough traffic to utilize fully a cable of the type described. When the engineers can give reasonable assurance of the cable it is believed that it will not have to await complete economic justification, because of the tremendous importance which it would have in ensuring privacy and continuity of trans-Atlantic telephone service.

There are already partly developed inventions which might greatly modify the picture of transoceanic telephony as set out above. One such is the 'vocoder', an instrument which dissects speech, transmits it in code and recreates it at the other end of the line. With vocoders a hundred or more simultaneous conversations might be carried by a pair of repeatered cables. While the vocoder would transmit the primary elements of conversation it would not provide all those qualities of speech which words alone do not convey. The vocoder gains in band width at the cost of naturalness of speech, but even so it may find important application.

Other inventions may extend the band-width available for transoceanic communication far beyond the range here discussed. Projects such as repeater ultra-short-wave radio systems and undersea waveguides, which to-day appear fantastic, may some day come within the range of practicability.