Transocanic Radio Telephone Development *

By RALPH BOWN

TEN years have elapsed since the opening to public use on January 7, 1927, of the first long distance radio telephone circuit. This form of intercontinental communication has now come into practical business and social use. A network of radio circuits interconnects nearly all the land wire telephone systems of the world. The art has passed through the pioneering stage and is well into a period of growth.

The technical side of this development, which the present paper reviews, divides naturally into four categories. The first covers those factors which made possible the beginning of commercial radio telephony.[1] In the second are the things without which its rapid growth and wide expansion could not have occurred. In the third, are a few incidental but interesting or valuable technical features. The fourth considers future improvements now in view.

Essential Initial Developments

Radio telephony presents difficulties in addition to those existing in radio telegraphy because: (1) The communication is two-way, and the radio system must be linked in with the wire telephone systems and available to any telephone instrument; (2) The subscriber cannot deliver himself of his message until the connection is actually established, and on this account delay due to unfavorable transmission conditions is less tolerable; (3) The grade of transmission required to satisfy the average telephone user is higher than that tolerable in aural tone telegraph reception by an experienced operator.

These requirements emphasized the need for accurate and quantitative knowledge of radio transmission performance as a basis for engineering radio telephone systems. There was at the same time a similar need for transmission data in the engineering of early radio broadcast installations. The effort brought to bear on these twin problems resulted in the development of practical field methods of measuring

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[1] A description of the early years of radio telephone development preceding extensive commercial application, together with a discussion of the origins of the whole art, will be found in companion paper "The Origin and Development of Radio Telephony," by Lloyd Espenschied, published in *Proc. I. R. E.*, September, 1937.

radio signal strength and radio noise. The employment of long distance radio telephony in commercial use was preceded by experimental operation and tests which gave a considerable fund of statistical information covering the cyclical changes characteristic of overseas radio transmission.

The realization that a relatively high degree of reliability was essential to success discouraged any attempt at commercial service until high-power transmission on a practical basis was assured by the invention of a method of making water-cooled tubes.

In searching for the most efficient way of applying the power made available by water-cooled tubes telephone engineers were led to the employment of a method which had already been successfully used in high-frequency wire telephony. This method, now well known to radio engineers, is called single-sideband suppressed-carrier transmission. As compared with the ordinary modulated carrier transmission, it increases the effectiveness of a radio telephone system by about 10 to 1 in power. This accrues partly because none of the power capacity of the transmitter is used up in sending the non-communication bearing carrier frequency and partly because the narrower band width permits greater selectivity and noise exclusion at the receiver.

A very important final element was also necessary to prevent voice-frequency singing through residual unbalances and around the entire radio link when wire circuits and radio channels are connected together.

Recourse was again had to a device newly worked out for wire telephone transmission. By associating together and electrically interlocking several of the voice current operated switching devices which had been developed for suppressing echoes on long wire lines, an arrangement now commonly known as a "vodas"[2] was developed. When the subscriber talks, his own speech currents, acting on the vodas, cause it to connect the radio transmitter to the wire line and at the same time to disconnect the radio receiver. When the same subscriber listens the connection automatically switches back to the receiver. No singing path ever exists. The amplification in the two oppositely directed paths can be adjusted substantially independently of each other, and constant full load output from the radio transmitters is secured. With this device it became possible to connect almost any telephone line to a radio system and to adjust amplification so that a weak talker over a long wire line could operate the radio transmitter as effectively as a strong local talker.

[2] This word, "vodas," is synthesized from the initial letters of the words "voice-operated device, anti-singing."

Developments Essential to Growth

The first long distance radio telephone circuit operated (and it still operates) between the United States and England with long-wave transmission at about 5000 meters. We did not then, and we do not today, know how any considerable amount of intercontinental radio telephony could have been accomplished with circuits of this kind. The frequency space available in the long-wave range would accommodate comparatively few channels. The high attenuation to overland transmission and the high noise level at these wave-lengths preclude their satisfactory use for very great distances or in or through tropical regions. The discovery that short waves could be transmitted to the greatest terrestrial distances and could be satisfactorily received in the tropics came at a most opportune time.

Short-wave transmission not only released the limitations on distance and location inherent to long waves but also opened up such a wide range of frequency space as to give opportunity for an extensive growth in numbers of both radio telegraph and radio telephone circuits. Short waves further encouraged the growth of radio telephony by making it cheaper. Thus, it became possible to make directive antenna structures of moderate size which increased the effectiveness of transmission many times, thereby reducing the transmitter power required for a given reliability of communication. Short waves were the indispensable element without which material growth could not have occurred, but there were other significant things.

An important desideratum in telephony is privacy. Commercial radio telephony would have been severely hampered if privacy systems had not been developed to convert speech into apparently meaningless sounds during its radio transit.

Another item of great aid in promoting growth was the development of methods of accurate stabilization of transmitted frequencies. The first effect of this was to eliminate the extreme distortion which characterized early short-wave telephone transmission and which was found to be due to parasitic phase or frequency modulation effects in the transmitters. As the number of radio communication facilities, both telegraph and telephone, grew, accurate stabilization of frequency became a necessity in order to permit effective utilization of the available frequency space without mutual interference between stations.

Later Technical Advances

The "rhombic" antenna is mechanically simple and electrically nearly aperiodic, covering a wide wave-length range efficiently. It has radically changed the character of the physical plant and investment necessary to the employment of directivity in short-wave transmitting and receiving.

In Hawaii and the Philippines on circuits to the United States the "diversity" method of reception is used wherein three individual separated antennas and receivers with interlocked automatic gain controls are combined to produce a common output having less distortion and noise than a single receiver.

The effects of distortion in short-wave circuits are avoided to some extent by an arrangement called a "spread sideband system," which has been used on circuits between Europe and South America. By raising the speech in frequency before modulation the speech sidebands are displaced two or three kilocycles from the carrier and many of the product frequencies resulting from intermodulation fall into the gap rather than into the sidebands.

On the Holland-Java route a system is being used whereby more than one sideband is associated with a single carrier or pilot frequency, each such sideband representing a different communication.

An improved signal-to-noise ratio is given by a device called a "compandor" [3] employed on the New York-London long wave circuit. It raises the amplitude of the weaker parts of the speech previous to transmission. In depressing these raised parts to their proper relative amplitude, after reception, the compandor also depresses the accumulated radio noise.

Present Outlook

The foregoing makes it evident that many fundamental engineering problems have been solved and that the pioneering stage of the service, when its possibility of continued existence might reasonably have been in doubt, has definitely been passed. In looking toward the future we find that the greatest needs are for improvement in reliability and in grade of service, accompanied by reduced costs.

Improving the reliability struggles against the fact that short wave transmission varies through such a wide range of effectiveness, and seems to be so much influenced by the sun. We have not only a daily cycle in the transmission of a given frequency but also an annual cycle and beyond this an eleven-year cycle associated with the change in sunspot activity. Superimposed upon these are erratic and occasionally large variations associated with magnetic storms.

[3] The synthetic word "compandor" is a contraction of the compound word "compressor-expander," which describes the effects the device has on the volume range of speech.

A statistical study of the data secured from operation of transoceanic radio telephone circuits over the past several years has given valuable help in engineering circuits to meet a given standard of reliability. This study has shown that the percentage of lost time suffered on a circuit appears to follow a probability law and that its relation to the transmission effectiveness of the circuit in decibels is given by a straight line when plotted to an arithmetic probability scale. Such a relation tells us, for example, that if a circuit as it stands suffers 15 per cent lost time, the lost time can be reduced to a selected lower value, say 5 per cent, by improving the circuit a definite amount, in the assumed case 10 decibels. It then becomes possible, by making engineering cost studies of the various available ways of securing the necessary number of decibels improvement in performance, to choose the most economical one. This approach is being applied to study of the radio telephone circuits extending outward from the United States. Some of the technical possibilities which are being considered for improving these circuits are discussed below.

The performance of a radio telephone circuit may be changed by dynamically modifying the amplification or other characteristics of the circuit in accordance with the speech transmitted. The compandor already mentioned is an example of this kind of improvement on long waves. Further developments particularly suited to the vagaries of short-wave transmission are possible.

The operation of the vodas, or voice-operated switching device linking the wire and radio circuits, is adversely affected by noise. Methods are being investigated for using single frequencies, called "control tones," transmitted alongside the speech band and under the control of speech currents, to give more positive operation of the switching devices and reduce the adjustment required.

The transmission improvement of about 9 decibels (about 10 : 1 in power) offered by single-sideband suppressed-carrier transmission has been delayed in its application to short-wave transmission partly because of the high degree of precision in frequency control and selectivity necessary to its accomplishment. In recent years successful apparatus has been developed and proved satisfactory in trials. The introduction of single sideband into commercial usage is already in progress.

Turning now from the transmitting to the receiving end, one fundamental way to reduce noise in radio telephony is to employ sharper directivity. It has been found by observation that there is a limit to which directivity, as ordinarily practiced, can be carried to advantage. It is easy to design antennas so sharp that at times very large improvements in signal-to-noise ratio are secured. But it is found that at other times these antennas are actually poorer than are much less sharply directive systems. Such observations also indicate a wide variation in the performance of antennas as regards selective fading, and the signal distortion accompanying it.

The result of all this work has been the development of a system based on an entirely new approach to the problem of sharp directivity and of telephone receiving. This system is called a MUSA System, the word MUSA being synthesized from the initial letters of the descriptive words Multiple Unit Steerable Antenna. An outline of the principles and methods is given below.

By sending short spurts or pulses of short-wave radiation from one side of the Atlantic, and receiving on the other side, it has been observed that each spurt may be received several times in quick succession. But these echoes do not arrive like successive bullets from the same gun, all following the same path. They come slanting down to the receiver from different angles of elevation, these vertical angular directions remaining comparatively stable. While the signal received at each of the individual directions may be subject to fading, the fading is somewhat slower and is not very selective as to frequency. The signal component coming in at a low angle takes less time in its trip from the transmitter than a high angle component. Evidently the low-angle paths are shorter. All these facts fit in well, on the average, with the ideal geometrical picture of waves bouncing back and forth between the ionosphere and the ground and reaching the receiver as several distinct components which started out at different angles, have been reflected at different angles, and have suffered different numbers of bounces.

The ordinary directive antenna is blunt enough in its vertical receiving characteristic to receive all or nearly all of these signal components at once. Because of their different times of transit the various components do not mix well but clash and interfere with one another at the receiver. This shows up as the selective fading and distortion which characterize short-wave reception much of the time. The MUSA method remedies this trouble.

The MUSA provides extremely sharp directivity in the vertical plane. By its use a vertical angular component can be selected individually. It consists of a number of rhombic antennas stretched out in a line toward the transmitter and connected by individual coaxial lines to the receiving apparatus. The apparatus is adjustable so that the vertical angle of reception can be aimed or "steered" to select any desired component as a telescope is elevated to pick out a star. The antennas remain mechanically fixed. The steering is done electrically with phase shifters in the receiving set. By taking several branch circuits in parallel from the antennas to different sets of adjusting and receiving apparatus the vertical signal components may be separated from each other.

Nature breaks the wave into several components and jumbles them together. The first function of the MUSA system, as just described, is to sort the components out again. Its second function is to correct their differences so that they may be combined smoothly into a replica of the original signal. To do this the received wave components are separately detected and passed through individual delay circuits to equalize their differences in transit time. They are then combined to give a single output. As compared with a simple receiver the MUSA receiving system gives (1) improvement in signal-to-noise ratio, as a result of the sharp directive selectivity of the antenna; (2) improvement against selective fading distortion, by virtue of the equalization of the time differences between the components before they are allowed to mix; and (3) improvement against noise and distortion, because of the diversity effect of combining the several components.

Fortunately, it is found that the directive selection and the delay compensation adjustments correct for one frequency are satisfactory for a considerable band of frequencies adjacent thereto. Thus there is offered the possibility of receiving a number of grouped channels through one system and the prospect appears not only of improved transmission but also of reduced cost per channel.

The possibility of grouping channels at the transmitting station may be conceived on the basis of either "multiple" or "multiplex" transmission. In the multiple arrangement each channel has its own antenna and its individual transmitter whose frequency is closely spaced from and coordinated with the adjacent channels of the group. In "multiplex" transmission, the channels are aggregated into a group at low power and handled *en bloc* through a common high-power amplifier and radiating system. Particularly in the multiplex case, there are possibilities of important economies if the technical problems are satisfactorily solved. Passing a multiplicity of channels simultaneously through a common-power amplifier involves interchannel interference due to modulation products which is not met with when only one channel is present. Severe requirements are thereby placed on the distortion characteristics of the power amplifier.

It seems a fair conclusion that the tendency in the engineering solution of the problems of economy and growth in radio telephone development (and perhaps also radio telegraph development) will be toward channel grouping methods, especially for backbone routes between important centers where large traffic may develop. This will be a considerable departure from past practice which has resulted in the existing system of scattered frequency assignments. It is to be hoped that the obvious difficulties in rearranging frequency assignments will not prove so unyielding as to preclude putting new engineering developments into service.