Transoceanic Telephone Service—Short-Wave Transmission

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The discussion relates to the transmission problems involved in short-wave radiotelephony over long distances and the transmission bases for design of the systems used in commercial transatlantic service. Choice of operating frequencies, amounts of transmitter power, directive transmitting and receiving antennas, automatic gain controls in receivers, and voice-operated switching devices are all factors which may be invoked to aid in solving these problems. The way in which they have been applied in the transatlantic systems and the results which have been obtained are set forth briefly.

TRUNK circuits between London and New York which furnish telephone service between these two cities and also permit successful conversation by means of toll wire extensions between the United States and Europe more generally are being carried over both long waves and short waves. It is the purpose of this paper to consider the transmission side of the new short-wave circuits which the American Telephone and Telegraph Company and the British General Post Office have made available for this service. In doing this we shall proceed from the more general considerations, relating to wave-lengths and communication channels, through a discussion of the principles governing the general design of the system, into a brief summary of practical performance results.

The frequency range so far developed for commercial radio use is roughly 20 to 30 million cycles wide, extending from about 10 kilocycles to perhaps 25,000 kilocycles per second. There are two parts of this whole spectrum suitable for transoceanic radiotelephony—the long-wave range which is relatively narrow, extending roughly from 40 kilocycles to 100 kilocycles, and the short-wave range which in its entirety is much broader, extending from about 6000 kilocycles to 25,000 kilocycles.

It is evident that the long-wave region, including perhaps only 50 kilocycles, offers opportunity for development of relatively few telephone channels, particularly in view of the fact that it is in use by a number of telegraph stations. Also it must be borne in mind that for telephony these waves are suitable for only moderate distances of the order of 3000 miles and for routes in the temperate zones where static

[1] Presented at the Winter Convention of the A. I. E. E., New York, N. Y., Jan. 1930.

interference is moderate. The first transatlantic radiotelephone circuit opened in 1927 was a long-wave circuit (58.5–61.5 kilocycles). In providing the next few channels for the initial growth of the service the opportunity to determine the utility of short waves was embraced.

The short-wave range is vastly wider in kilocycles but, nevertheless, has its limitations as to the number of communication facilities it affords. For a given route of a few thousand miles a single frequency gives good transmission for only a part of the day. For example, from the United States to Europe a frequency of about 18,000 to 21,000 kilocycles (17 to 14 meters) is good during daylight on the Atlantic. But in the dawn and dusk period a frequency of about 14,000 kilocycles (22 meters) is better. For the dark hours something like 9000 kilocycles (33 meters) gives best transmission and for midnight in winter an even lower frequency near 6000 kilocycles (50 meters) is advantageous. Thus, in considering the short-wave range in terms of communication circuits, we must shrink its apparent width materially to take account of the several frequencies required for continuous service.

At the present time the frequency spaces between channels are much greater than the bands of frequencies actually occupied by useful transmission. This elbow room is to allow for the tendency of many stations not to stay accurately on their nominal frequencies but to wander about somewhat. But in spite of this allowance, cases of interference are common and one of the activities which must be carried on in connection with a commercial system is the monitoring of interfering stations and the accurate measurement of transmitting frequencies to determine the cause of the conflict. To permit intensive development of the frequency space offered by Nature the greatest possible constancy and accuracy of frequency maintenance in transmitting sets will be required.

The fact that channels have been assigned (within wide bands set aside for a particular service) with little regard to the geographical location of stations may result in neighboring channels having much stronger signals than those in the channel being received. When this is so, a severe requirement is placed on the selectivity of the receiver to prevent interference.

Interconnecting with Wire Circuit Extensions

The skeleton of a radiotelephone circuit is in its essentials very simple. It consists merely of a transmitter and a receiver at each end of the route and two oppositely directed, one-way radio channels between them. These two independent channels must be arranged at the terminals to connect with two-wire telephone circuits in which messages in opposite directions travel on the same wire path. The familiar hybrid coil arrangement so common in telephone repeaters and four-wire cable circuits might appear to solve this problem, were there not difficulties peculiar to the radio channels. In the short-wave case large variations in attenuation occur in the radio paths within short intervals of time. These would tend to cause re-transmission of received signals at such amplitudes that severe echoes and even singing around the two ends of the circuit would occur unless means were provided to prevent this.

To overcome these fundamental transmission difficulties, an automatic system of switches operated by the voice currents of the speakers has been developed.[2] These devices cut off the radio path in one

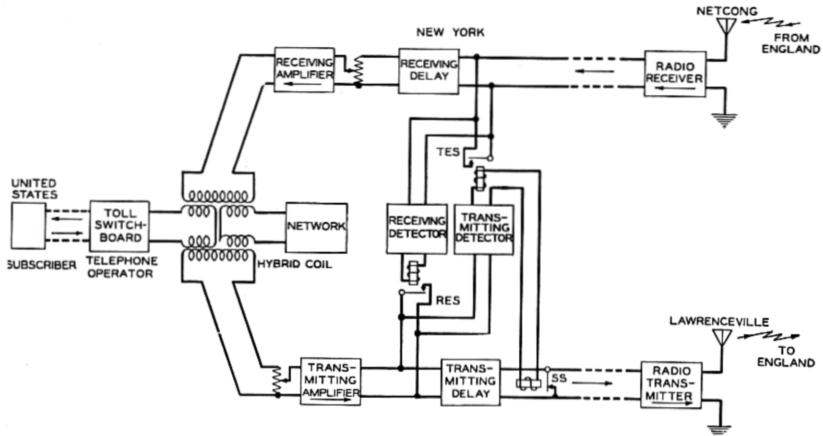

Fig. 1—Circuit diagram illustrating operation of voice-operated switching device.

direction while speech is traveling in the reverse direction and also keep one direction blocked when no speech is being transmitted. The operation is so rapid that it is unnoticed by the telephone users. Since this system prevents the existence of singing and echo paths, it permits the amplification to be varied at several points almost without regard to changes in other parts of the system, and it is possible by manual adjustment to maintain the volumes passing into the radio link at relatively constant values, irrespective of the lengths of the connected wire circuits and the talking habits of the subscribers.

Fig. 1 gives a schematic diagram of the United States end of one of the short-wave circuits showing the essential features of a voice-operated device which has been used. This kind of apparatus is

[2] For detailed description of this system see "The New York-London Telephone Circuit" by S. B. Wright and H. C. Silent, *Bell System Tech. Jl.*, Vol. VI, October, 1927, pp. 736–749.

capable of taking many forms and is, of course, subject to change as improvements are developed. The diagram illustrates how one of these forms might be set up. This form employs electro-mechanical relays. The functioning of the apparatus illustrated is briefly as follows: the relay TES is normally open so that received signals pass through to the subscriber. The relay SS is normally closed to short circuit the transmitting line. When the United States subscriber speaks his voice currents go into both the Transmitting Detector and the Transmitting Delay circuit. The Transmitting Detector is a device which amplifies and rectifies the voice currents to produce currents suitable for operating the relays TES and SS which thereupon short circuit the receiving line and clear the short circuit from the transmitting line, respectively. The delay circuit is an artificial line through which the voice currents require a few hundredths of a second to pass so that when they emerge the path ahead of them has been cleared by the relay SS. When the subscriber has ceased speaking the relays drop back to normal.

The function of the Receiving Delay circuit, the Receiving Detector, and the relay RES is to protect the Transmitting Detector and relays against operation by echoes of received speech currents. Such echoes arise at irregularities in the two-wire portion of the connection and are reflected back to the input of the Transmitting Detector, where they are blocked by the relay RES which has closed and which hangs on for a brief interval to allow for echoes which may be considerably delayed. The gain control potentiometers shown just preceding the transmitting and receiving amplifiers are provided for the purpose of adjusting the amplification applied to outgoing and incoming signals.

The relief from severe requirements on stability of radio transmission and from varying speech load on the radio transmitters which this system provides permits much greater freedom in the design of the two radio channels than would otherwise be possible.

The Radio Channels

One of the first questions which comes up in considering the design of a radio system is the power which can be sent out by the transmitter. The word "can" is used advisedly, rather than "should," since in the present art the desideratum usually is the greatest amount of power that is technically possible and economically justifiable. There are few radio systems so dependable that increased power would not improve transmission results. At very high frequencies the generation of large powers is attended by many technical difficulties but fortunately the radiation of power can be carried out with much greater efficiency than is feasible at lower frequencies. At 18,000 kilocycles (about 16 meters) a single half-wave radiator or doublet is only about 25 ft. long and it is possible to combine a number of them, driven in phase by a common transmitter, into an antenna array which concentrates the radiated power in one geographical sector. In that direction the effectiveness may be intensified 50 fold or more (17 db) and waste radiation in other directions reduced materially. Thus, one of the transmitters at Lawrenceville, New Jersey, used in the short-wave transatlantic circuits when supplying 15 kw. radiates in the direction of its corresponding receiving station as effectively as would a non-directive system of about 750 kw.

The transmitting antennas also give some directivity in the vertical plane, increasing the radiation sent toward the horizon and decreasing that sent at higher angles. It is not yet certain that vertical directivity is always advantageous and this effect has not been carried very far.

At the receiving station the radiated power has dwindled to a small remnant which must be separated from the static as far as possible and amplified to a volume suitable for use in the wire telephone plant. Here again directive antenna arrays are of value. A receiving antenna system sensitive only in a narrow geographical sector, and that lying in the direction from which the signal arrives, excludes radio noise from other directions and thereby scores a gain of perhaps 40 fold (16 db) in the power to which the signal can be amplified without bringing noise above a given value. It also scores against noise which arises in the tubes and circuits used for amplification, since the combined action of the several antennas of the array delivers more signal to the initial amplifier stage where such noises originate.

Thus, it is evident that transmitter power, transmitting directivity, receiving directivity, and quiet receiving amplifiers are of aid in providing signal transmission held as far as possible above the radio noise. In a well designed system the relative extents to which these aids are invoked will depend upon economic considerations as well as upon the technical possibilities of the art.

There is one other type of noise than that provided by Nature which is of particular importance at short waves,—electrical noise from the devices of man. One of the worst offenders is the ignition system of the automobile. The short-wave transoceanic receiving station at Netcong, New Jersey, is so located that automobile roads are at some distance, particularly in the direction from which reception occurs. Service automobiles which produce interference cannot be allowed near the antenna systems unless their ignition systems have been shielded. Also, electrical switching and control systems incidental to the power, telegraph, and telephone wire systems at the station are shielded or segregated.

At both the transmitting and receiving stations at least three antenna systems are supplied for each circuit, one antenna for each of the three frequencies normally employed. The design and arrangement of these are dictated by the requirements flowing from their uses. The purpose of the transmitting antenna is to concentrate as much power as possible in one direction. The purpose of the receiving antenna is to increase reception from the desired direction and to cut down reception at all other angles. In the former the forward-looking portion of the characteristic is of greatest importance, while in the latter the rearward characteristics need greatest refinement.

Transmission Performance

In short-wave telephone systems the width of the sidebands is so small a percentage of the frequency of transmission that tuning characteristics of the antennas and high-frequency circuits are relatively broad and impose little constriction on the transmission-frequency characteristic. A flat speech band is easy to obtain over the range of approximately 250 to 3000 cycles employed for these commercial circuits. This relieves the short-wave circuits from many of the problems of obtaining sufficient band width which are troublesome in designing long-wave systems.

Short-wave transmission is subject to one frailty which particularly hampers its use for telephony. This is fading. Where fading is of the ordinary type, consisting of waxing and waning of the entire transmitted band of frequencies, automatic gain control at the receiving station is of value and is employed in the transoceanic circuits under discussion. The amplification in the receiver is controlled by the strength of the incoming carrier and is varied inversely with this strength so as to result in substantially constant signal output. Obviously this control can be effective only to the extent that the signal seldom falls low enough to be overwhelmed by radio noise.

When fading is of the selective type, that is, the different frequencies in the transmitted band do not fade simultaneously, the automatic gain control system is handicapped by the fact that the carrier or control signal is no longer representative of the entire signal band.

Selective fading is believed to result from the existence of more than one radio path or route by which signals travel from transmitter to receiver. These paths are of different lengths and thus have different times of transmission. Wave interference between the components arriving over the various paths may cause fading when the path lengths change even slightly.

If the path lengths differ by any considerable amount, for example, a few hundred miles, the wave interference is of such a character as to affect the frequencies across a band consecutively rather than simultaneously.

With the presence of selective fading there comes into being the necessity of guarding against rapid even though small variations in the transmitted frequency, since if such variations are present a peculiar kind of quality distortion of the telephone signal results.

The varying load which speech modulation places on the transmitter circuits tends to cause slight variations in the instantaneous equivalent frequency which are known as "frequency modulation" or "phase modulation" depending on their character. To prevent this effect the control oscillator must be carefully guarded against reaction by shielding and balancing of circuits and the design must be such as to preclude variable phase shifts due to modulation in subsequent circuits of the transmitter.

It is apparent that if there are two paths of different lengths, two components which arrive simultaneously at the receiver may have left the transmitter several thousandths of a second apart. If the transmitter frequency has changed materially during this brief interval trouble may be expected. The trouble actually takes the form of a distortion of the speech as demodulated by the receiving detector.[3]

Defects in short-wave transmission due to radio noise, minor variations in attenuation, fading, and distortion are nearly always present to some extent and, when any or all are severe, cause a certain amount of lost service time. These interruptions are of relatively short duration and, furthermore, there is enough overlap in the normal times of usefulness of the several frequencies available, so that shifting to another frequency may give relief. There is, in addition, a kind of interruption which from the standpoint of continuity of service is more serious. At times of disturbance of the earth's magnetic field, known as "magnetic storms," short-wave radio transmission is generally subject to such high attenuation that signals become too weak to use and sometimes too weak to be distinguishable. These periods affect all the wavelengths in use and may last from a few hours to possibly as much as two or three days in extreme cases. They are followed by a recovery period of one to several days in which transmission may be subnormal.

Severe static may cause interruption to both long- and short-wave services at the same time but the short waves are relatively less affected by it and are usually able to carry on under static conditions which

[3] For a discussion of this phenomenon see "Some Studies in Radio Broadcast Transmission" by Bown, Martin, and Potter, *I. R. E. Proc.*, Vol. 14, No. 1, p. 57.

prevent satisfactory long-wave operation. On the other hand severe fading or the poor transmission accompanying a magnetic disturbance may interrupt short-wave service without affecting the long waves adversely,—in fact magnetic disturbances often improve long-wave transmission in the daytime. The service interruptions on the two types of circuits are thus nearly unrelated to each other and have no definite tendency to occur simultaneously. This is the principal reason why both long-wave circuits and short-wave circuits appear essential to reliable radiotelephone service.

On routes which are very long or which cross tropical areas which result in static sources facing the directive receiving antennas, long

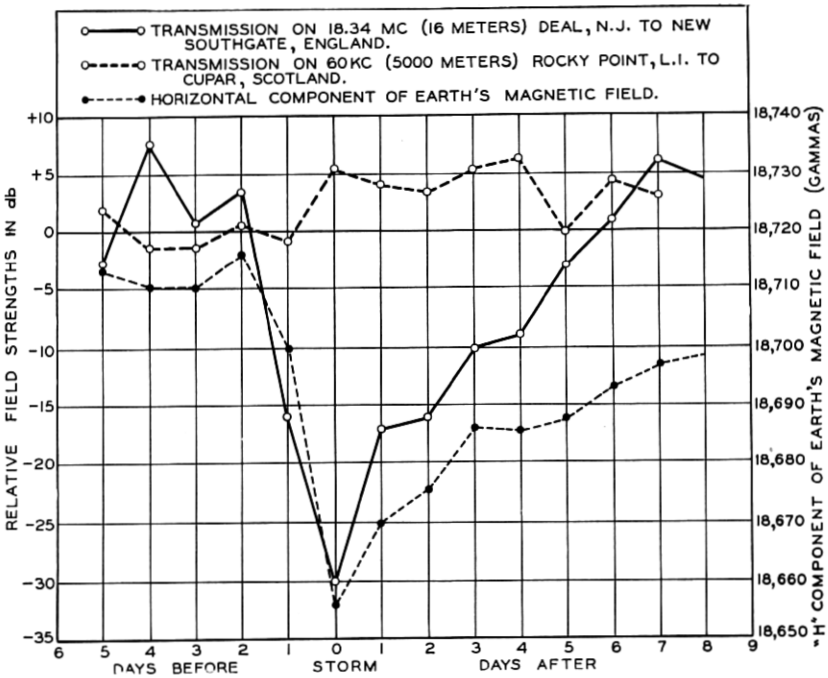

Fig. 2—Effect of magnetic disturbances on radio transmission.

waves cannot as yet be successfully employed and short waves alone are available. However, experience tends to indicate that on North and South routes such as between North and South America, the interruptions associated with magnetic storms are less severe and of shorter duration.

The cycle of events which accompanied a particularly severe magnetic storm[4] in July, 1928, is shown graphically in Fig. 2. The light

[4] Data regarding other magnetic disturbances are given in a paper by C. N. Anderson, entitled "Notes on the Effect of Solar Disturbances on Transatlantic Radio Transmission," *I. R. E. Proc.*, Vol. 17, No. 9, September, 1929.

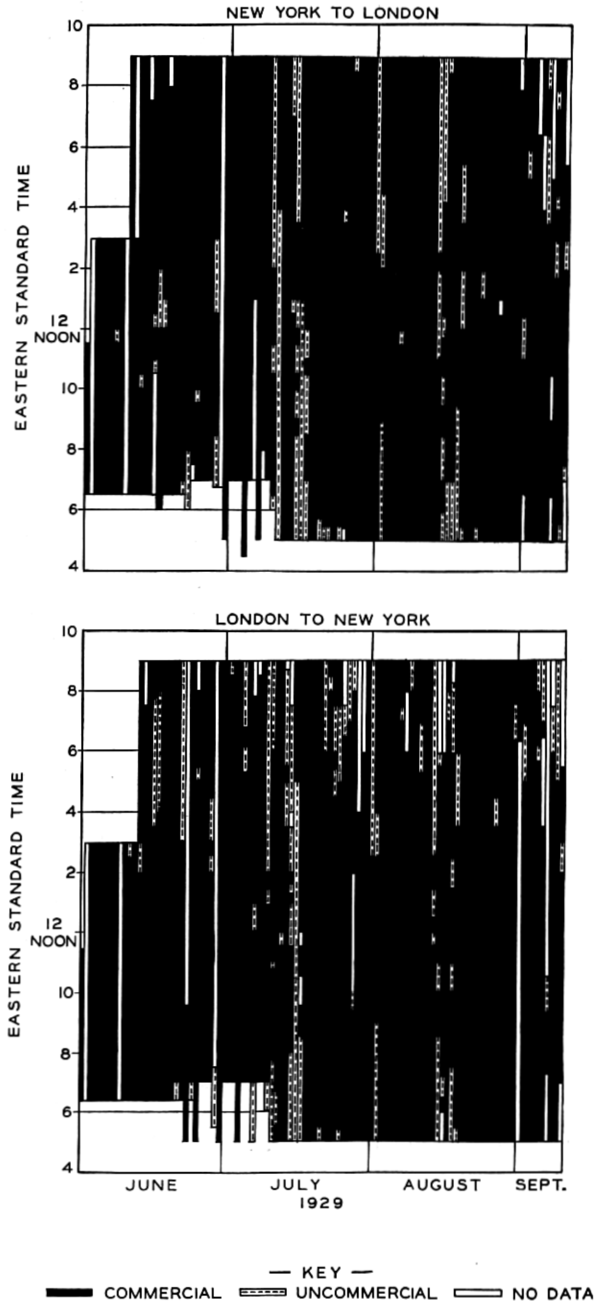

Fig. 3—Chart showing transmission performance of a short-wave transatlantic telephone circuit.

dotted curve shows the variation in the horizontal component of the earth's field. The heavy solid line follows the daily averages of the short-wave received signal field. It is apparent that the disturbance took two days to reach its peak and the recovery to normal took nearly a week. The heavy dotted line shows received field on long waves (60 kilocycles) and indicates that transmission was improved slightly at the same time the short waves were suffering high attenuation.

The experience with transatlantic telephone service on short waves covers a period of nearly three years, there having been available a one-way channel from the United States to England used as an emergency facility for the first year and a half, a two-way circuit for the next year, and two circuits since June, 1929. It is only in this later period, however, that a circuit has been available operating regularly with the amounts of transmitter power and antenna directivity which have been mentioned.

The performance of the two one-way channels forming this circuit is charted in Fig. 3. The charts are plotted between hours of the day and days in the year so that each unit block represents one hour of service time. The solid black areas are time in which commercial operation could be carried on. The dotted strips are uncommercial time. The blank areas are for time in which, for one reason or another, the circuit was not operating and no data were obtained. Perhaps the most outstanding feature of these charts is the tendency of the lost time to fall in strips over a period of two or three days. These strips coincide approximately for both directions of transmission. The principal ones are about July 10 and 15 and August 2 and 17. These are characteristic of the interruptions accompanying magnetic disturbances of the kind which occur at irregular intervals of a few days to several weeks. They are, of course, not as severe as the disturbance illustrated in Fig. 2.

It is apparent that for these three summer months this new circuit gave a good account of itself and furnished commercial transmission for something like 80 per cent of the time that service was demanded of it. In these same months the long-wave system suffered its greatest difficulty from static, and we have concretely illustrated the mutual support which the two types of facilities give each other.

It should not be inferred from these data that the short-wave transatlantic radio links furnish 80 per cent of the time talking circuits as stable and noise free as good wire lines. Under good conditions they do provide facilities which compare favorably with good wire facilities. On the other hand they may at times be maintained in service and graded "commercial" under conditions of noise or other transmission defects for which wire lines would be turned down for correction, since

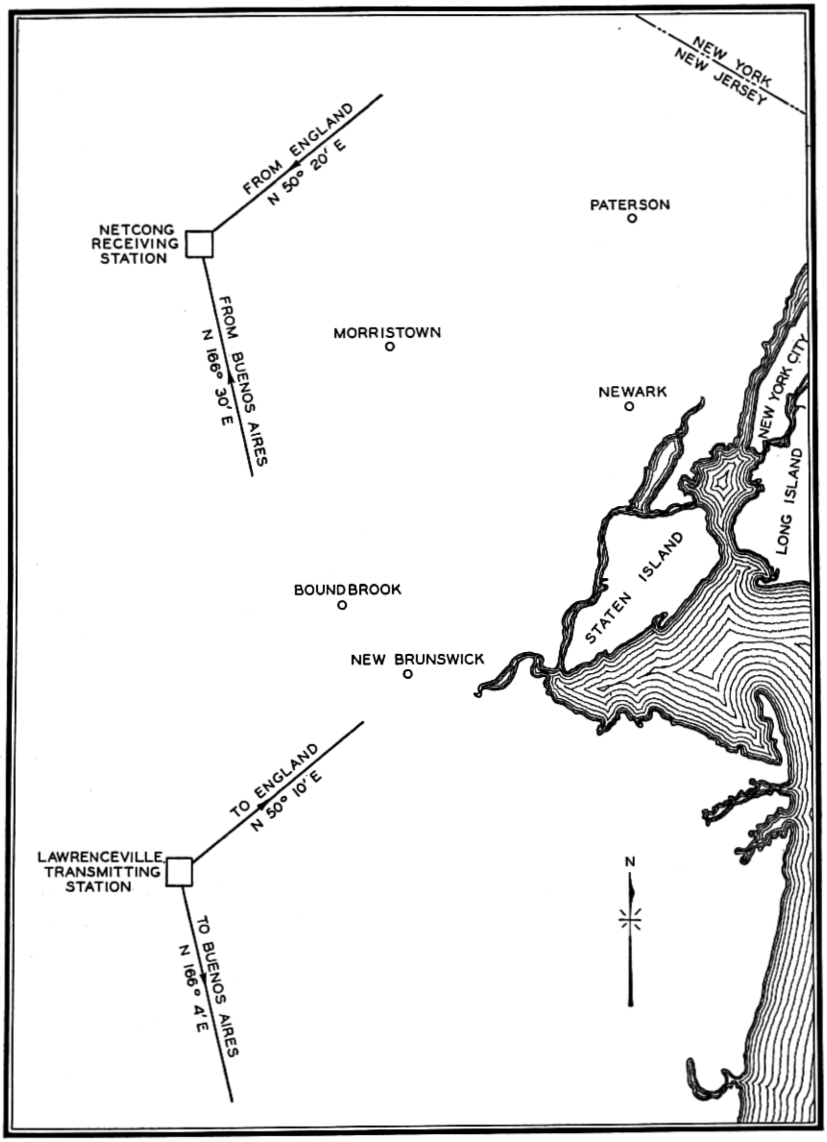

Fig. 4—Map showing transmission considerations affecting location of stations.

the obviously undesirable alternative is to give no service at all until conditions have improved again. The present development effort is largely directed toward improvements which will insure not only a greater degree of reliability against interruptions but which also will improve the grade of service as a whole.

In the foregoing little has been said about the stations and plant since a description of these and the operation of them are treated in two companion papers by Messrs. Cowan and Oswald. It may be well, however, to view the physical scene broadly as set forth on the accompanying map, Fig. 4.

The geographical arrangement of the transmitting and receiving stations was governed among other things by transmission considerations. The two stations were placed about 50 miles apart because this is approximately the distance for minimum signal and at a lesser or greater distance the signals from the American transmitter might be strong enough to offer some interference to receiving the English or South American stations on adjacent channels. For the same reason they were placed at considerable distances from the transmitters and receivers of other communication agencies. The Netcong receiving station lies to the north of the Lawrenceville transmitting station so as not to be in paths of strong signals from the directive antennas which face northeast toward England and southeast toward South America. This configuration also places the transmitter outside the sensitive angles of the directive receiving antennas.