The New York-London Telephone Circuit

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SYNOPSIS: This paper discusses the special provisions which are in use on the transatlantic telephone to compensate for the variability of the wire and ether paths, for the radio noise, and for the fact that two-way transmission is effected upon a single wave-length. So-called technical operators are in attendance at each end of the radio path and are equipped to adjust the magnitude of the speech currents entering the radio transmitters to such a value as to load these transmitters to capacity. The amplification introduced at the radio receivers can also be adjusted to compensate for changes in the transmission efficiency of the radio paths. Finally, voice-operated relays together with suitable delay circuits are provided which so control the apparatus that at any given time it can transmit in but one direction. By this arrangement, a speaker's voice upon leaving his transmitting station cannot operate his own receiver although this is tuned to the transmitting wave-length.

TO the telephone subscribers who use the New York-London circuit the procedure of making a call and carrying on a conversation is as simple as that of any long distance telephone call. Even to the telephone operator who establishes a transatlantic connection there is little to differentiate the New York-London "wire-radio-wire" circuit from the hundreds of other circuits which appear as mere jacks on the switchboard in front of her. Beyond this point, however, there is an organization of physical plant, personnel and procedure very much different from the usual long distance telephone circuit.

Without going into any description of the radio portion of the New York-London circuit, which has been adequately treated in previous articles, this paper describes some of the interesting features of the circuit, including the method of electrical operation which has been worked out for making possible two-way talking in the usual way, in spite of difficulties introduced by "static," transmission variations and difficulties brought about by the use of the same "frequency band" for transmission in both directions. The method of operation involves manual adjustments of controls at the radio stations and at the circuit terminals, and automatic switching by means of vacuum tube-operated relays controlled by the voice currents of the telephone subscribers. The voice-operated relay system is particularly interesting, and is, therefore, rather fully described.

Before the operation of the circuit is described a brief general picture of the system will be given. Fig. 1 shows its geographical layout, and gives an idea of the relative lengths of wire and radio circuit involved.

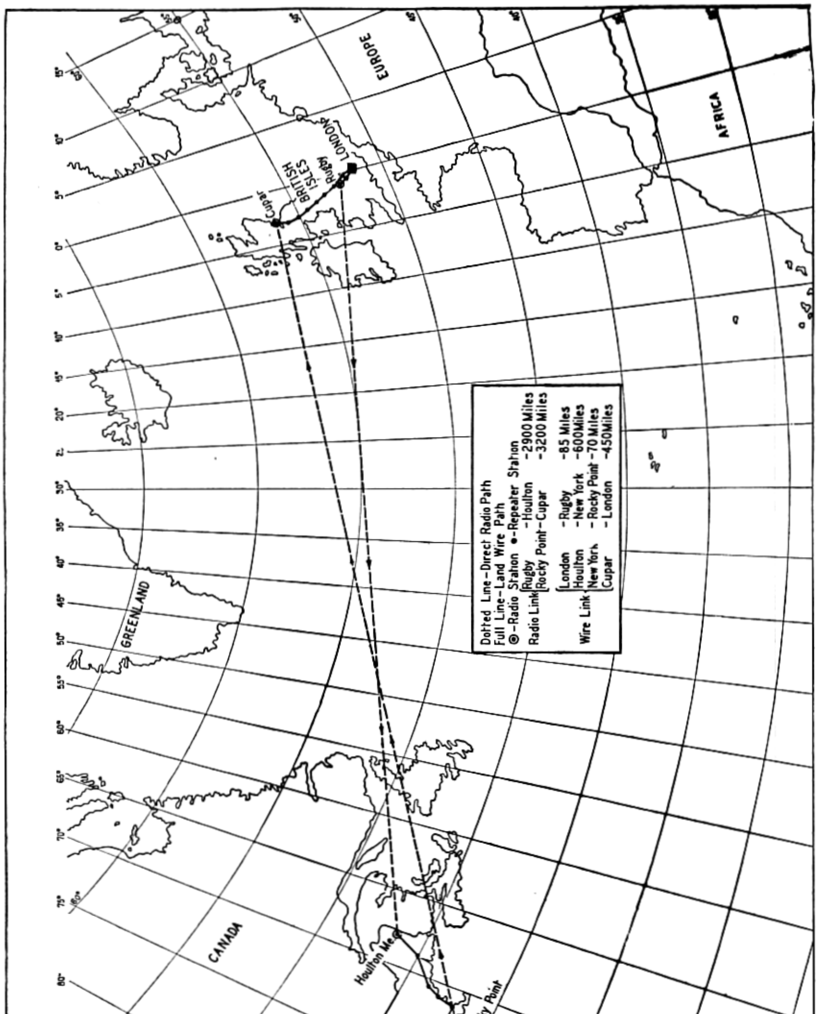

Dotted Line–Direct Radio Path
Full Line–Land Wire Path
⊙–Radio Station ●–Repeater Station
Radio Link Rugby –Houlton –2900 Miles
Rocky Point–Cupar –3200 Miles
Wire Link London –Rugby –85 Miles
Houlton –New York –600 Miles
New York –Rocky Point –70 Miles
Cupar –London –450 Miles
EUROPE
AFRICA
BRITISH ISLES
LONDON
Rugby
Cupar
GREENLAND
CANADA
UNITED STATES
NEW YORK
Houlton Me.
Rocky Point

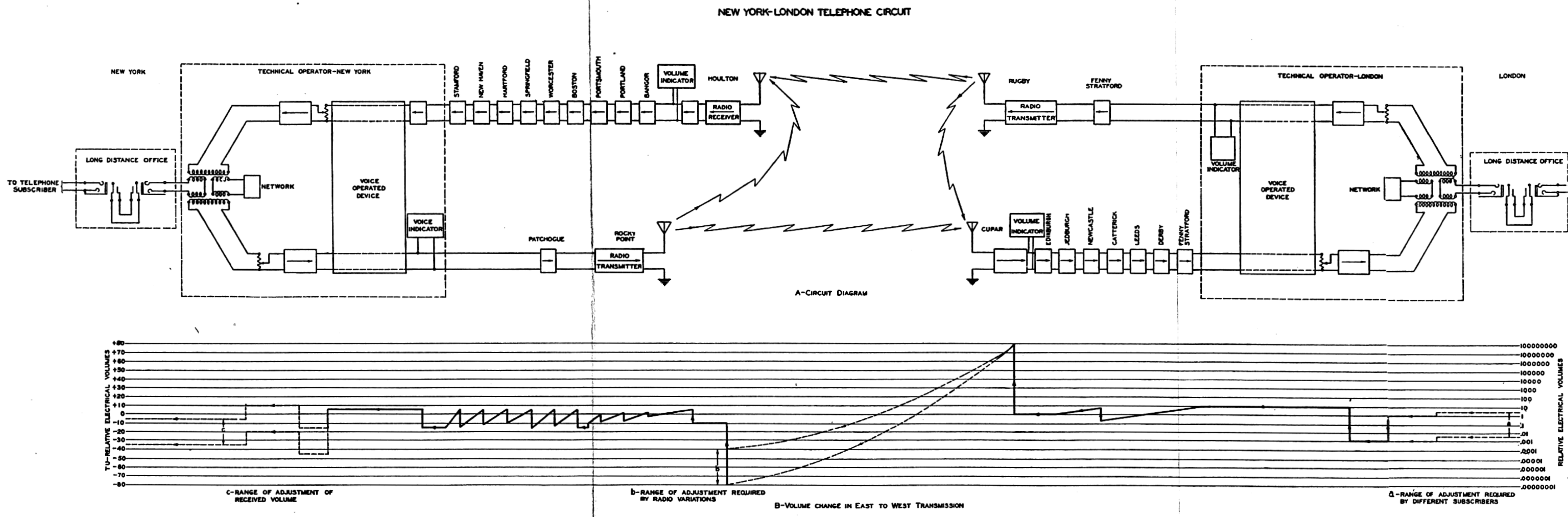
Fig. 1.

Fig. 2 (*A*) is a schematic circuit diagram emphasizing the land wire sections to permit showing the locations of intermediate repeater stations and terminal apparatus. This figure shows that the trans-atlantic is similar to a long "four-wire" land telephone circuit in which speech travels over different paths in the two directions. These two branches are combined into a single circuit at the terminals where special apparatus, including automatic switching devices, and specially trained men known as "technical operators" are stationed. The usual long distance girl operator establishes connections to subscribers.

As will appear shortly, the duties of a technical operator have nothing to do with the setting up of connections but require him to be continuously attentive to the electrical operation of the circuit, and to make adjustments of the amplification in the wire lines whenever the strength of voice currents bound for the radio transmitter changes. He is enabled to do this by watching the indicating needle of a sensitive vacuum tube-operated meter, called a "volume indicator." The volume indicator shows the strength or weakness of the electrical speech waves in the line. Alongside of this meter are located the dials with which he controls the amplification. Fig. 3 shows a technical operator watching the meter at the New York terminal. The apparatus shown on the panels in this picture includes the necessary terminal amplifiers and devices for adjusting and maintaining various parts of the wire and radio system.

Fig. 2 (*B*) shows the relative strength of voice waves or "electrical volumes" at various points in the circuit when a telephone subscriber in England is talking to one in the United States. The broken lines in this diagram indicate the magnitude of variations in the electrical volumes delivered to the circuit and received from it, as well as transmission variations in the radio section or "link." The relative values of electrical volume in both directions of transmission are, of course, essentially similar. The voice currents require about 1/15 of a second to travel from either terminal to the other over the circuit. It is interesting to consider that only about one fourth of this time is occupied in traversing the radio link, although radio constitutes about 85 per cent of the total length of the circuit, the remainder being in the wire lines and terminal apparatus.

It is important to note from Fig. 2 (*B*) that the ratio of the strongest to the weakest electrical volumes sent into the circuit at a terminal may be as much as 1,000 times. This is indicated at (*a*) in the figure. The variation is due partly to the different ways in which the subscribers talk, and partly to the variation in losses in the lines which connect the subscribers to the circuit. The technical operator adjusts



NEW YORK-LONDON TELEPHONE CIRCUIT
NEW YORK
TECHNICAL OPERATOR-NEW YORK
LONG DISTANCE OFFICE
TO TELEPHONE SUBSCRIBER
NETWORK
VOICE OPERATED DEVICE
VOICE INDICATOR
STAMFORD
NEW HAVEN
HARTFORD
SPRINGFIELD
WORCESTER
BOSTON
PORTSMOUTH
PORTLAND
BANGOR
VOLUME INDICATOR
HOULTON
RADIO RECEIVER
PATCHOGUE
ROCKY POINT
RADIO TRANSMITTER
A-CIRCUIT DIAGRAM
RUGBY
FENNY STRATFORD
RADIO TRANSMITTER
TECHNICAL OPERATOR-LONDON
LONDON
LONG DISTANCE OFFICE
TO TELEPHONE SUBSCRIBER
NETWORK
VOICE OPERATED DEVICE
VOLUME INDICATOR
CUPAR
VOLUME INDICATOR
EDINBURGH
JEDBURGH
NEWCASTLE
CATTERICK
LEEDS
DERBY
FENNY STRATFORD
TU-RELATIVE ELECTRICAL VOLUMES
+80 +70 +60 +50 +40 +30 +20 +10 0 -10 -20 -30 -40 -50 -60 -70 -80
RELATIVE ELECTRICAL VOLUMES
100000000 10000000 1000000 100000 10000 1000 100 10 1 .1 .01 .001 .0001 .00001 .000001 .0000001 .00000001
C-RANGE OF ADJUSTMENT OF RECEIVED VOLUME
b-RANGE OF ADJUSTMENT REQUIRED BY RADIO VARIATIONS
a-RANGE OF ADJUSTMENT REQUIRED BY DIFFERENT SUBSCRIBERS
B-VOLUME CHANGE IN EAST TO WEST TRANSMISSION

Fig. 2.

the amplifiers so as to keep the electrical volumes reaching the radio transmitter at a predetermined value. The technical operator also adjusts the received volume over the range indicated at (*c*) to give the best operation under different conditions of static, and for different types of connections.

An interesting fact to be observed here is that the voice power is amplified about 100,000,000 times in the radio transmitter and anywhere from 30,000 to 300,000,000 times at the radio receiver and associated amplifiers, depending on the loss in the radio path at any particular time as indicated at (*b*). Including the amplification which it is necessary to use on the wire "links," the total power amplification in either direction is approximately 10^{40}. Although more amplification is used in this circuit at a single point, such as at the radio transmitter, than at a single point in any other commercial telephone circuit, the total power amplification is less than in one of the telephone cable circuits from New York to St. Louis, where it is approximately 10^{50}.

Having in mind the foregoing facts, one can appreciate the difficulties which had to be faced in the way of operating this circuit and which have been successfully overcome. The more important may be summarized as follows:

(1) The transmission losses through the ether in the radio links vary from time to time in an irregular manner at intervals which preclude the possibility of making predetermined or systematic compensating adjustments of the amplification at the radio receivers.

(2) The radio links are frequently more noisy than wire circuits. This noise consists principally of stray electric waves (static) and varies considerably from time to time.

(3) The tendency for strong echo currents to exist in this circuit is considerably greater than in ordinary wire circuits. This is due partly to the methods employed for overcoming the difficulties brought about by (1) and (2), and partly to the fact that radio transmission in the two directions is carried out in the same frequency band.

These difficulties have been overcome by the following means:

(1) To overcome the variations in the transmission efficiency of the radio links, adjustments are made from time to time of the amplification in the radio receivers. Radio operators are in constant attendance at the receiving stations in order to make these adjustments.

(2) To assist in overcoming the effect of radio noise, adjustments are

made of the amplification in the wire links so that the radio transmitter is fully loaded up. This permits radiation of full power regardless of how loudly or weakly the subscriber talks, and regardless of the length of the circuit between the subscriber and the transatlantic terminals. This keeps the radio speech waves as large as possible compared to the noise at all times. These adjustments are made by the technical operators under the guidance of the "volume indicators."

(3) To suppress echo effects, a system of voice-operated switching relays has been devised whose function is to interrupt, when not in use, any transmission path which may double back to its source and give rise to echoes or singing in the circuit.

The manual adjustments of controls required in (1) and (2) should require no further explanation.

Before describing the voice-operated switching system of (3), it will be desirable to explain what this system is required to do. As previously stated, the adjustments employed to eliminate the two radio effects—namely, variability and noise—tend to increase the severity of echo effects. This follows from the fact that such adjustments result in a net transmission loss from terminal to terminal which is not constant as in ordinary telephone circuits, but which varies from time to time depending on the loss in the ether path and the strength of the voice currents which are delivered to the circuit terminal. The overall transmission of the circuit may vary from a loss to a considerable gain. If means were not taken to prevent it, this gain would set up between the two subscribers, circulating currents of rather large amplitude producing either severe electrical echo effects or the totally inoperative condition known as "singing."

A further echo difficulty was brought about through the use of a common frequency band or group of wave-lengths for transmitting in both directions. This was highly desirable to reduce the amount of frequency space occupied in the ether since there is but a limited suitable frequency space available. The radio waves at the frequencies used (namely, 58.5 to 61.5 kilocycles) cannot be directed to a definite point or confined to a single path. The radio receiver cannot, of course, when both transmitters are operating at the same frequency, select one transmitter from the other by any ordinary tuning means. Referring to Fig. 1, since the distance from the receiver at Houlton, for example, to Rocky Point is much less than the distance from Houlton to Rugby, the antenna at Houlton is exposed to a signal from the transmitter in America which is much stronger than the signal from

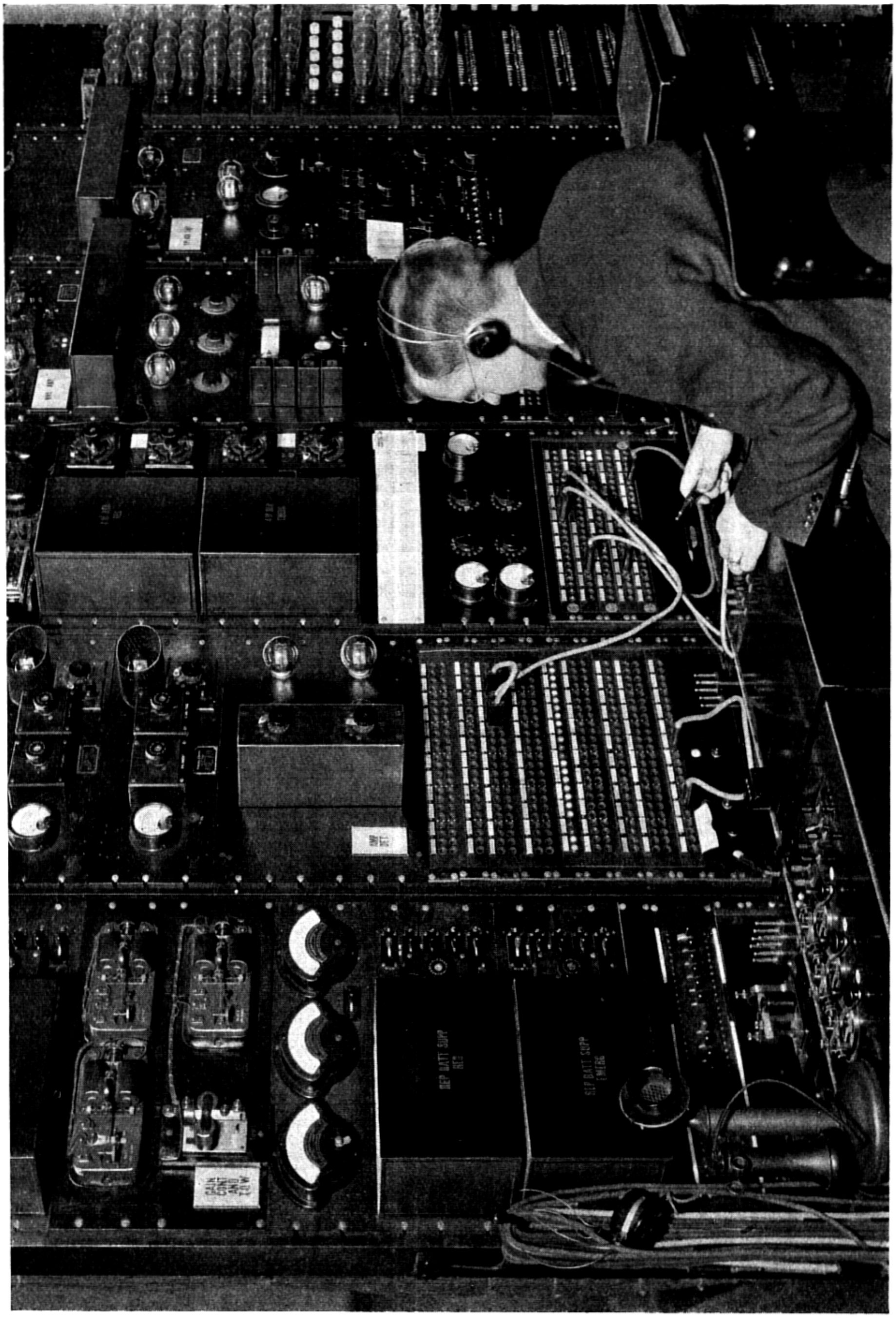


Fig. 3.

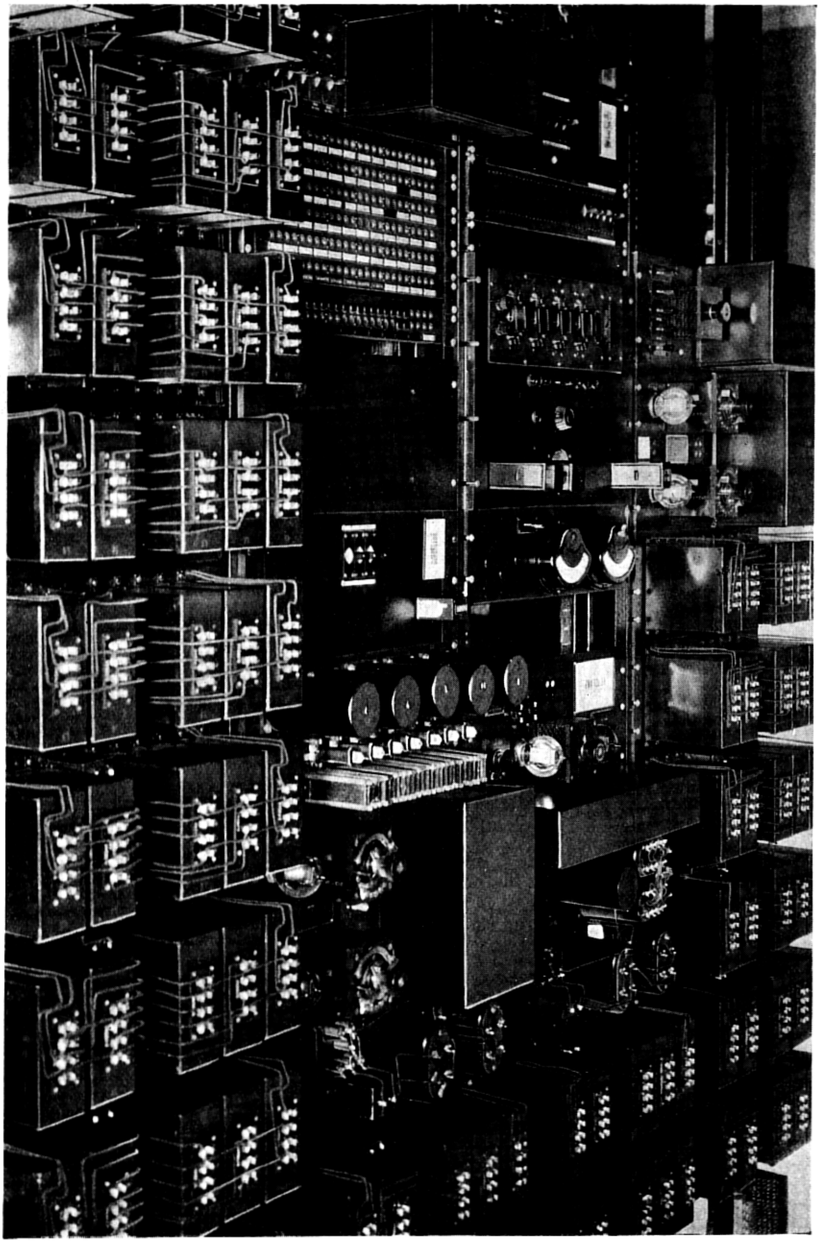


Fig. 4.

England.[1] Were it not for the use of the voice-operated devices, this would result in a very strong echo being returned to the local talker with disconcerting effects, and, dependent upon the adjustment of other parts of the circuit, might even result in violent singing of the circuit.

Referring again to Fig. 2 (*A*), it will be seen that there are three paths capable of giving rise to objectionable echoes or singing, one path at each end of the circuit through the wire lines, radio transmitter and local receiver, and a third path from end to end of the circuit and back again. The first two paths are introduced by using the same frequency band for transmission in both directions. The third path which depends upon the impedance unbalance between the two-wire lines at the terminals and their respective networks is similar to the one which gives rise to echoes in long four-wire land telephone circuits. All three paths are affected by the amplification adjustments.

Suppression of echoes and singing in the circuit requires that all three of these echo paths be kept blocked at all times against unwanted transmission. Furthermore, since there is no single point common to all the echo paths, the system for suppressing echoes comprises two separate installations—one of which is located in New York and the other in London. The devices used to control the echo paths are operated by the voice currents of the two telephone subscribers, in such a manner as to allow transmission to pass first in one direction when one subscriber is talking, and then in the other direction when the second subscriber replies. Transmission in the opposite direction to that in which the waves are traveling is blocked. When no one is talking, the outgoing transmission paths at both ends of the circuit are blocked. The necessary functions at the New York end of the circuit are performed by a combination of electro-magnetic relays, vacuum tube detectors and delay circuits. A photograph of the installation is shown in Fig. 4. At London a device performing similar functions has been developed by engineers of the British General Post Office.[2]

A schematic diagram of the device employed at the New York end is shown in Fig. 5. By tracing the action of the relays it will be seen that for all conditions of the relays, the echo paths shown are blocked at the proper times. Thus, Fig. 5, which shows the conditions when no one is talking, indicates that the circuit from the radio receiver to the terminal is normally in a receiving condition but the transmitting branch of the circuit is kept inoperative by relays *SS* and *CS*.

[1] Directive antenna systems with a blind spot might be used to overcome this effect, but their directive properties would not then be available for use against static and other interference. The general directivity of the receiving systems used, however, reduces the unwanted transmissions about 100-fold.

[2] C. A. Beer and G. T. Evans, "The Post Office Differential Voice-Operated Anti-Singing Equipment," *P. O. E. E. Jnl.*, April, 1927.

APPLICATION OF VOICE OPERATED DEVICES TO NEW YORK-LONDON TELEPHONE CIRCUIT

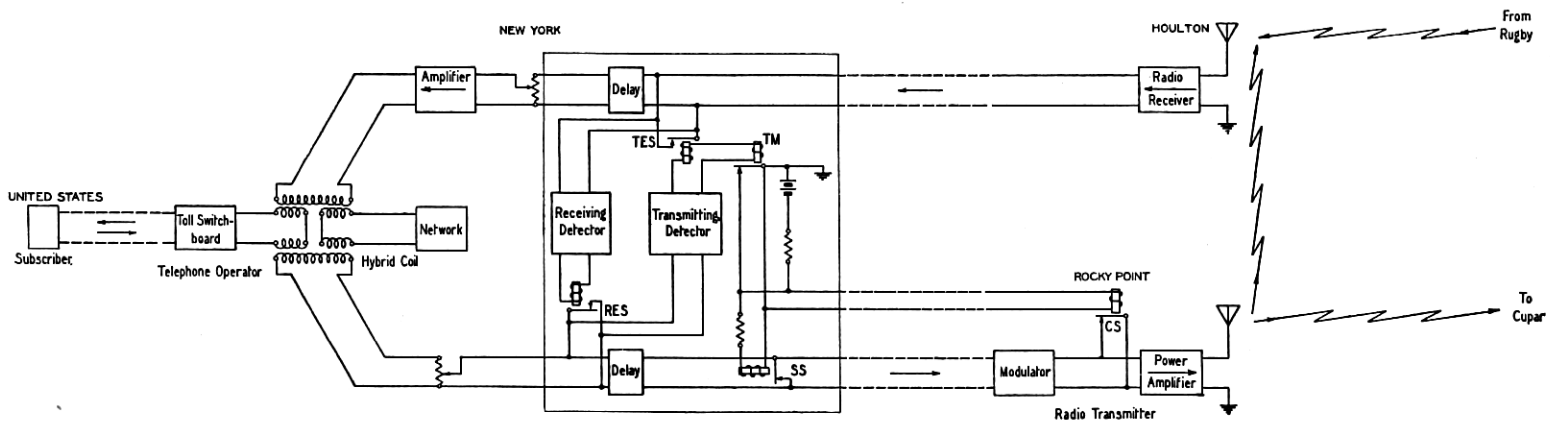


Fig. 5.

When the United States subscriber speaks, a small portion of his voice currents enters a detector, operating relays *TM* and *TES*. The action of relay *TM* causes the operation of relays *SS* and *CS*, thus clearing the outgoing line. The operation of relay *TES* short-circuits the receiving line. The main part of the outgoing voice currents passes on through the delay circuit, wire line and radio transmitter to the distant subscriber. Any transmission picked up by the radio receiver is blocked by relay *TES*. When the subscriber stops talking, the relays are restored to the normal condition.

While relays *SS* and *TES* are sufficient to switch the speech paths back and forth and prevent singing, Fig. 5 shows that there are two other relays which also interrupt undesired transmission. One of these is relay *RES*, which operates when a subscriber in England is speaking and short-circuits the United States transmitting line. This short-circuit prevents the transmitting relays from being operated by the echo of received currents returned from the local subscriber's line. The other relay, shown in Fig. 5 as *CS*, is not used at present but was needed when the circuit was first opened due to the fact that the radio transmitter and receiver in the United States were much closer together than they now are. The action of relay *CS* is similar to that of *SS*, but it was located at the radio transmitting station for an interesting reason. Although the radio transmitter is of a type which should radiate energy only during the actual transmission of speech, it would, were it not for relay *CS*, put a certain amount of noise energy into the air. While this noise, which originates partly in the radio transmitter and partly in the wire lines connecting it to the terminal, is too weak to be heard at the distant terminal, it was strong enough when picked up by the radio receiver at Riverhead, Long Island, to interfere with reception of the distant transmitter. Relay *CS* suppressed any such noise when the transmitter was idle, that is, when no one was speaking from New York. There are a number of ways of operating relay *CS*; either by voice currents rectified at the radio transmitter or via a wire circuit from the action set up by voice currents at the terminal. This latter method is shown in Fig. 5. When the United States radio receiver was moved to Houlton, Maine, the use of relay *CS* was discontinued, as the noise currents picked up there from Rocky Point were negligible.

A graphical representation of the time functions of two of the relays on the transmitting side of the voice-operated device is shown in Fig. 6. This illustrates the action during a representative spoken syllable. It will be noted that relay *SS* does not operate at the exact beginning of the speech. As shown at *a* in Fig. 6, it is necessary for the speech wave

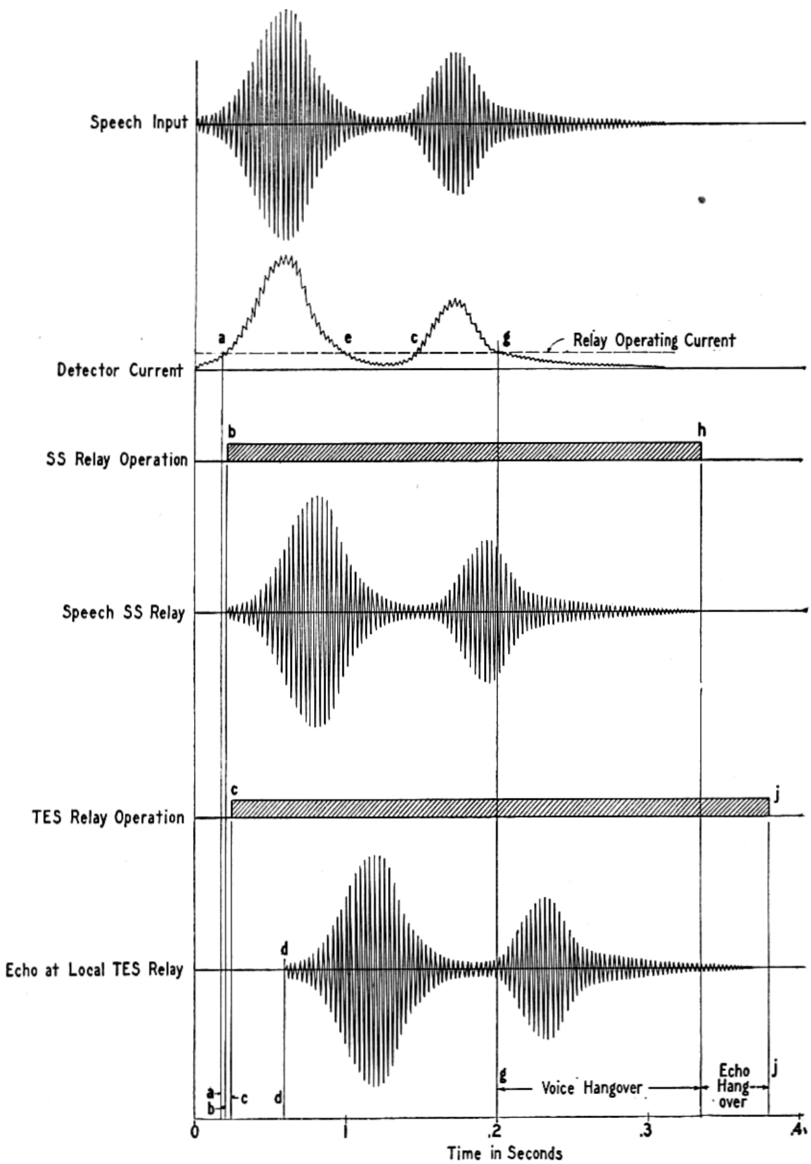

Speech Input
Detector Current
a
e
c
g
Relay Operating Current
SS Relay Operation
b
h
Speech SS Relay
TES Relay Operation
c
j
Echo at Local TES Relay
d
a
b
c
d
g
Voice Hangover
Echo Hang-over
j
0
.1
.2
.3
.4
Time in Seconds

Fig. 6.

to build up to a certain definite amplitude before operation can begin. After this a finite time *a–b* is required for the relay to operate. During the interval from *O* to *b*, the voice currents are passing through the delay circuit. Thus the relay clears the path in time to transmit fully all necessary parts of this speech wave even though they have a very weak beginning.

The final trailing weak part of the speech wave is allowed to pass, by making the *SS* and *CS* relays release slowly by means of suitable circuits not shown on the drawing. This effect is shown from *g* to *h* in Fig. 6, as the "voice hangover" action. This action also functions to hold relay *SS* operated during any momentary weak lapses of speech between parts of the syllable as shown at *e–f* in the speech wave in Fig. 6.

As previously mentioned, a strong echo of the outgoing transmission is picked up at the radio receiver and suppressed by relay *TES*, the operation of which is indicated at *c* in Fig. 6. This echo is delayed an amount represented by *O* to *d* in being transmitted over the wire circuits. Relay *TES* has a releasing time slower than that of relay *SS* by the amount *h–j*, which is sufficient to care for the time that the echo is delayed.

In the operation of this system it is necessary for relays *SS* and *CS* and the devices which operate them to be sufficiently sensitive to operate on all parts of the outgoing speech sounds in order that none may be lost. On the other hand, relay *RES* need operate only on impulses which, if allowed to be transmitted across the multi-winding transformer ("hybrid" coil) as echoes, would be strong enough to falsely operate the relays associated with the transmitting side. Use of a relay on the receiving side which normally blocks reception would be possible, but this would require very much greater sensitivity. Due to the noise (static) introduced by the radio links, the use of such a sensitive relay is undesirable. Therefore, the device has been made to have a transmission path normally free in the direction in which the noise is high and a normally blocked path in the direction in which only the noise on the two-wire line need be combated.

If it were not for the delay circuit on the transmitting side, it would be necessary to increase the sensitivity of the voice-operated relay device so that the relays would obtain enough current to cause their operation at the very beginning of the speech wave, rather than allow the wave to build up to an appreciable amplitude before operation occurs. This delay circuit, therefore, permits appreciable reduction in the sensitivity of the transmitting side of the device, reducing the probability of operation by noise from the connected subscriber's line.

It may be said in passing that by an increase in sensitivity it is perfectly possible, with the extremely fast relays used, to omit this delay circuit and obtain satisfactory operation. This would, however, make the device more subject to noise effects.

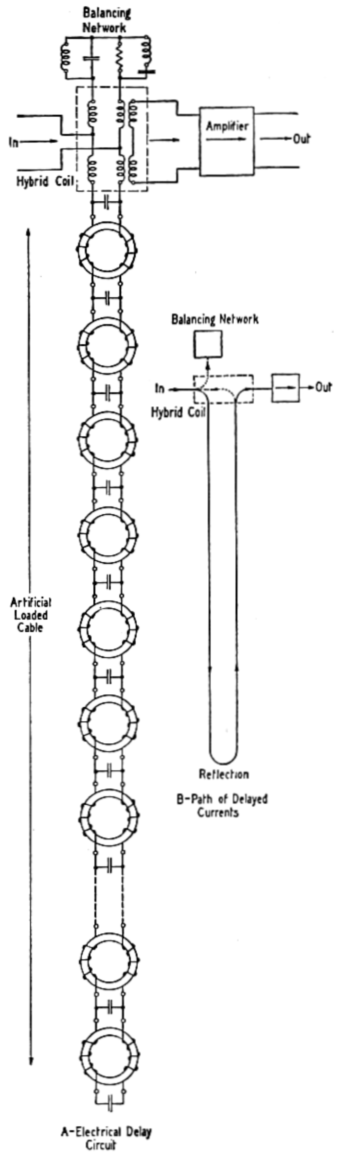


Fig. 7.

Referring to Fig. 5, a delay circuit is also included in the receiving branch of the circuit which, however, performs a somewhat different function from that in the transmitting branch. This delay circuit serves to delay transmission across the hybrid coil, thereby permitting the relay *RES* to operate and apply its protecting short-circuit before the echo from the connected circuit arrives at the input to the transmitting detector. In suppressing the echo from the radio receiver by relay *TES* a similar action is performed by the delay in transmission over the wire lines to the radio stations.

The type of delay circuit used in the voice-operated device just described is shown in Fig. 7 (*A*). This consists of an electrical network by means of which transmission sent into it is received at its output after a finite time interval. To obtain this delay action a loaded artificial line having low attenuation is employed, in conjunction with a network which balances its "surge" impedance, and a hybrid coil. An interesting feature of the arrangement is that the principle of reflection, which tends to cause objectionable echoes in telephone circuits, is here usefully employed to pass the voice currents through the artificial line twice. This results in a considerable saving of apparatus. Fig. 7 (*B*) shows the path of transmission through the delay circuit. Alternating current entering the hybrid coil divides equally between the delay circuit and the balancing network. That part which enters the balancing network is dissipated; that part which enters the delay circuit is transmitted through it, with small attenuation, to the end. Here it meets with a reflecting termination and is transmitted back whence it came. Reaching the hybrid coil, half of it goes back toward the input and half of it is transmitted on in the desired direction. The half which goes to the input meets the output side of a one-way amplifier and is dissipated. The remaining half passes through an amplifier which makes up for the transmission loss of the delay circuit and the loss due to the two divisions of energy at the hybrid coil.

The desirability of maintaining the proper relationships between the time actions of the relays and the delays in the other parts of the system will be apparent from the foregoing. A circuit for measuring the time of operation of the relays is provided which in combination with a detector and a relay may also be used for measuring the time required for alternating currents to travel through a delay network or other telephone circuit. This device is capable of measuring directly time intervals as short as .0001 second and up to 1 second in length. The measuring device is conveniently located along with the apparatus comprising the voice-operated device, as shown in Fig. 4.

In conclusion, it should be pointed out that the method of operation that has been described is expensive and has disadvantages which make it undesirable on any but a very special and necessarily complex telephone circuit, such as the transatlantic. It has, however, proved satisfactory in this service. The more interesting effects which this method of operation accomplishes may be restated as follows:

Given the condition of an anti-singing circuit such as the New York-London radio circuit, it is possible to make the amount of power radiated from the radio transmitting stations independent of the strength of the voice currents arriving over the land lines. For example, a subscriber speaking from a suburb of Chicago is heard just as loudly in London as another person speaking from the terminal of the circuit at New York.

As a result, voices of all talkers, strong or weak, are heard with the same freedom from static.

Both of the above effects result from the adjustment of the strength of outgoing speech so as to load the radio transmitter to maximum output for all messages. If the circuit were operated with amplification fixed at a value required by the strongest talkers, then the voices of weak speakers would often be lost unless the power of the radio transmitter were increased several hundred fold.