Two-Way Radio Telephone Circuits *

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This paper deals with the problems of joining long-distance radio telephone transmission paths to the ordinary telephone plant. It gives the possibilities and limitations of various methods of two-way operation of such circuits where the radio channels employ either long or short waves. It also describes the special terminal apparatus for switching the transmission paths under control of voice currents and lists the advantages of using voice-operated devices.

RADIO telephone circuits are now in regular use between New York and London, New York and Buenos Aires, San Francisco and Honolulu, and many other points. At each end of such a circuit there are a transmitting radio station and a receiving radio station, usually geographically separated. The radio provides two one-way transmission paths. The circuit is completed by means of one-way wire lines which connect the radio sending and receiving stations to a common point. At this common point some rather intricate apparatus is called for in order to permit switching of the circuit to the wire telephone plants at the two terminals. This paper explains why this intricate apparatus is necessary even for the comparatively simple case of short-wave radio circuits which use different frequency bands to transmit in opposite directions. It also describes the latest form of this terminal apparatus in which provision is made for certain switching of privacy apparatus by means of which an important saving is made in the amount of privacy apparatus required. The original form of this apparatus is described in an earlier paper.[1]

Transmission Paths

Radio telephone circuits may employ the same frequency band for transmission in the two directions or they may employ separate bands. The present long-wave telephone circuit between New York and London is of the first type, while most existing short-wave circuits are of the second.

A short-wave circuit, using separate frequency bands, is shown in its simplest form in Fig. 1. It is formed of two sets of terminal appara-

* Presented at I. R. E. Convention, Pittsburgh, Pa., April 7–9, 1932. Published in *Proc. I. R. E.*, July, 1932.

[1] S. B. Wright and H. C. Silent, "New York-London Telephone Circuit," *Bell Sys. Tech. Jour.*, **6**, 736–749; October, 1927.

tus connected by two one-way channels, each of which consists of a transmitting wire line, a radio link and a receiving wire line. The function of the terminal or "combining" apparatus is to tie together these two one-way paths in such a manner that they may be connected at the switching centers to various telephone subscribers via the usual telephone circuits.

When the United States subscriber, designated as *A* in Fig. 1, talks, electrical waves set up by his voice pass over a wire line to a toll office. They then divide in a hybrid set. Part of the energy is dissipated in the output of a receiving repeater, and part is amplified by a transmitting repeater and passes over a wire line to a radio transmitter, as indicated in the upper transmission path of Fig. 1.

The waves are then amplified and transformed into radio-frequency energy and radiated. Some energy is picked up by a distant radio receiver, amplified, and transformed back into voice-frequency energy which passes over a wire line to the overseas terminal. The receiving repeater at this point makes up for the loss of the receiving wire line. From its output the waves pass into a hybrid set, part being dissipated in the network and the other part going through the toll office to the overseas subscriber *B*. Due to the imperfect balance between the subscriber's line and the network, a portion of this energy will be returned over the lower transmission path to the United States subscriber *A* as echo.

The action when the overseas subscriber *B* talks is substantially the same as that described above except that the useful speech waves pass over the lower transmission path.

In long-wave radio circuits the scarcity of suitable radio channels makes it highly desirable to use the same frequency band for transmission in both directions. This results in two additional radio paths becoming important, namely, those between the radio transmitter and the radio receiver at each end of the circuit. By using specially directive antenna arrangements, transmission over these paths may be partly balanced out. In practice, this balance cannot be made very effective in reducing the relative importance of these paths without sacrificing materially the receiving directivity against natural radio noise. The effect of these added transmission paths is to make the transmission problem more difficult, as will be explained.

Transmission Characteristics

Returning to consideration of the simple four-wire set-up involved in short-wave operation, the transmission characteristics of the circuit evidently depend on the sum of the effects of the radio and wire line

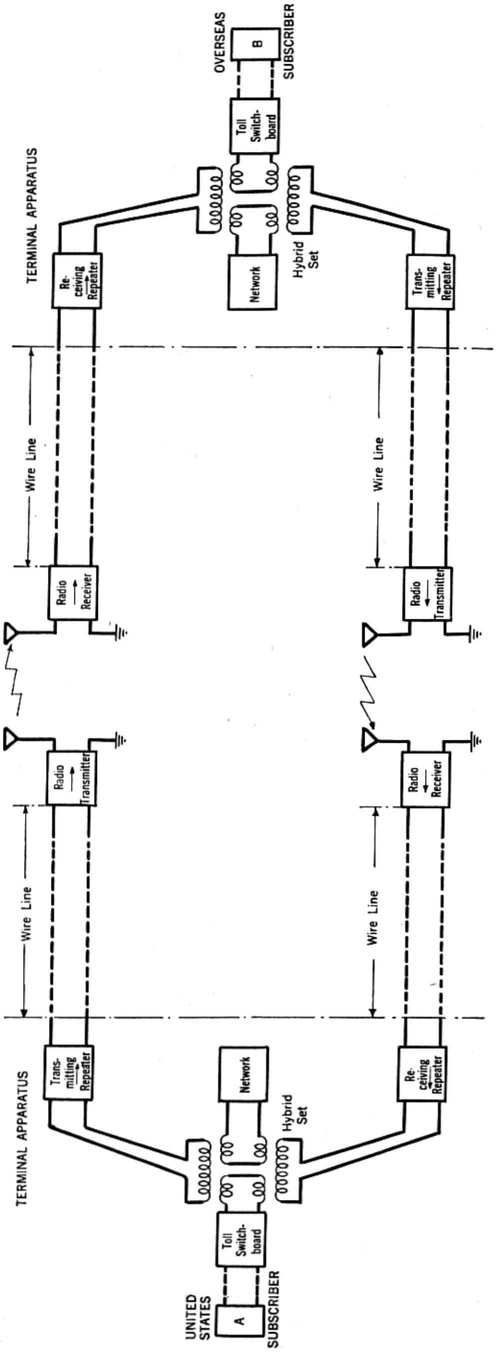

Fig. 1—Two separate radio links connected as a four-wire circuit.

portions. In view of the relatively higher cost and greater length of the radio links, the highest grade wire circuits available are usually justified so that, in general, they should not be allowed to contribute much transmission impairment. In general, the added delay introduced by these wire lines is their most important effect.

If the radio links are quite stable and fairly free from atmospheric disturbance, the circuit may be operated like four-wire land telephone circuits. That is, the total amplification in the circuit may be kept at such a value that it never exceeds the total attenuation, and over-all singing will not occur. Four-wire terminating sets or hybrid sets placed at the ends of the circuit, as shown in Fig. 1, are adequate to prevent singing and minimize echo effects in four-wire circuits which have over-all transmission times less than about 0.02 second, provided the net loss from switchboard to switchboard does not become lower than about 5 db.

If the radio links or wire lines are long, the circuit will produce annoying echoes exactly as a four-wire cable circuit will, due to delay or instability, or both. Also, as in the case of four-wire cable circuits, echo effects may be reduced appreciably by voice-operated echo suppressors which block the path of the delayed echoes while the other path is transmitting speech. The possibilities and limitations of this type of device are discussed elsewhere.[2]

When the radio channels are more noisy and/or less stable, the transmission may be greatly improved through more efficient use of the radio links. The noise may be minimized by bringing the speech waves of all talkers, strong or weak, to the same "electrical volume" or strength at the input to the radio transmitter. Thus, practically full modulation may be maintained on the radio transmitter at all times and the ratio of the desired signal to the radio noise kept a maximum. Large changes in gain between the two-wire line and the radio transmitter are necessary to accomplish this result. These changes are made by technical operators who make the adjustments with variable loss devices. An indication of the volume is obtained through the aid of electrical meters called "volume indicators." In practice, the over-all transmission of a long radio circuit may be varied by the technical operators from a 30-db loss to a 30-db gain within a few minutes.

In short-wave circuits, the phenomenon known as "fading" introduces an effect which is of great importance in two-way operation. Where fading results in variations of the entire transmitted band of frequencies, automatic gain control at the radio receiver is effective in

[2] A. B. Clark and R. C. Mathes, "Echo suppressors for long telephone circuits," *Jour. A. I. E. E.*, **44**, 618–626; June, 1925.

maintaining the received volume at a substantially constant value. The gain control is operated by the incoming carrier. When the fading is of the type in which the different frequencies in the transmitted band do not fade simultaneously, the automatic gain control is not so effective and considerable variations in volume out of the receiver may occur in a short time.

In the long-wave circuit, the variations are too slow to be classed as fading, and occasional manual adjustments of receiver gain result in keeping the volume at the receiving end within about ± 5 db.

Because of the gain adjustments to reduce noise, combined with changes in radio receiver gain to compensate for fading or for variations in radio attenuation, "singing" would occur if the hybrid coils and echo suppressor were not augmented by additional means of singing prevention. One way of preventing singing would be to reduce gain in the receiving leg whenever gain was introduced in the transmitting leg of the circuit. Volume penalties to the listener as great as 25 db would frequently be encountered if this were done, and, in addition, considerable agility would be required on the part of the technical operators to keep the circuit adjusted. However, this method would not compensate for gain changes in the radio receivers, so that singing might still occur under unfavorable conditions.

Also, in the case of a long-wave transatlantic circuit, singing could occur over transmission paths between the local radio transmitter and receiver. The volume received from the local transmitter may occasionally be as much as 40 db stronger than that from the distant station if the transmitter and receiver are about 90 miles apart, even though antenna directivity were used at both the transmitters and the receivers. In general, if the receiver gain is adjusted to give the proper volume on the distant station, the amplification in the local radio path is entirely out of reason.

It is therefore necessary to provide other means of preventing singing to maintain optimum transmission conditions.

Vodas

There has been developed for meeting these difficulties an anti-singing voice-operated device known as a "vodas." [3] Fig. 6 shows a radio telephone circuit arranged with a vodas in its simplest form at each end of the circuit. The vodas consists of a transmitting delay circuit, detector, and certain relays, and a receiving delay circuit, detector, and relay. These devices are operated by the voice currents in the circuit so as to keep all singing paths blocked at all times.

[3] Taken from initials of the words "Voice-Operated Device Anti-Singing."

The vodases in Fig. 6 are shown for the condition when no speech is being transmitted. Relay 1 keeps the transmitting circuit blocked so that singing cannot occur around the complete circuit or through a local radio path and terminal. Transmission is free to pass the contacts of relay 2. When the United States subscriber speaks, voice currents go into the transmitting detector and delay circuit. While they are traversing the delay circuit, relays 1 and 2 become operated provided relay 3 has not been operated previously. The operation of relay 1 permits the voice currents to travel on to the radio transmitter. The operation of relay 2 blocks the receiving path and prevents echoes and singing that might otherwise occur when relay 1 is operated.

Upon being received at the distant end, the voice currents operate relay 3 from the receiving detector, thus protecting the transmitting detector and relays against operation by echoes of received speech currents. These echoes are returned from unbalances in the two-wire portion of the connection beyond the terminal. The receiving delay circuit delays the speech long enough to insure complete operation of relay 3 before the echoes return. When the subscriber stops speaking, the relays return to normal.

By adding two more relays to the transmitting side of the vodas, it is possible to save part of the apparatus which is used to increase privacy on the circuit. This saving is made by using the same privacy device for both transmitting and receiving. This is possible provided the action of the privacy device is the same for distorting the voice waves at the transmitting end as it is for restoring them at the receiving end of the circuit. An arrangement of the vodas having this feature, which is now in general use, is illustrated in Fig. 2. The apparatus additional to the simple vodas consists of relays 4 and 5, the privacy device, a hybrid set, and two one-way repeaters. In Fig. 2 this apparatus is labeled "Privacy Switching Circuit."

The action of the device shown in Fig. 2 on transmitting speech waves is as follows: Useful waves from subscriber *A* are impressed on a potentiometer ahead of the transmitting repeater, which is kept adjusted by the technical operator to maintain constant volume at the output of the transmitting repeater. The waves then pass into the vodas where they first reach the transmitting delay circuit and are stored for a short interval. A small part of these waves enters the transmitting detector and operates relays 1, 2, 4, and 5, provided relay 3 has not been operated by the receiving detector previously. The interval of the transmitting delay circuit is several times as great as the operating time of relays 1, 2, 4, and 5 so that initial weak parts of speech syllables may be stored in this delay circuit until stronger parts arriving later have had a chance to operate the relays.

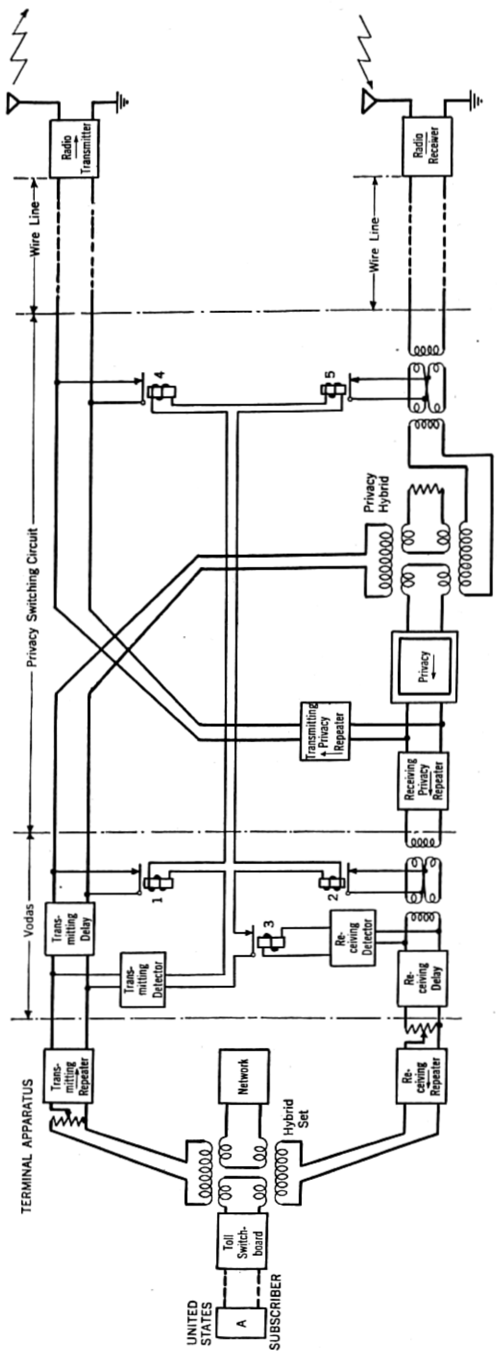

Fig. 2—Voice-operated device used on New York-Buenos Aires and other radiotelephone circuits.

Operation of relay 1 clears a path for the speech waves after they pass through the transmitting delay circuit. From there they pass into the privacy switching circuit traveling downward to the privacy hybrid set. Here they divide and the useful portion travels through the privacy device. At its output the waves divide, part being amplified by the transmitting and part by the receiving privacy repeater. The subscriber at *A* is prevented from hearing echo by the operation of relay 2 which disables the receiving transmission path in a way to be described later. The portion of the waves which travels upward through the transmitting privacy repeater, however, is now free to pass on to the wire line and radio link due to the operation of relay 4. Operation of relay 5 prevents any echo due to direct transmission from the local radio transmitter to the radio receiver from being passed into the privacy device and thus causing distortion of the outgoing waves.

Action of this device on incoming speech waves is as follows: The waves after being detected by the radio receiver travel over the wire line and, provided the transmitting relays have not been previously operated, pass through the first repeating coil combination and into the lower side of the privacy hybrid. There they divide and the useful part passes through the privacy device where it is restored to an intelligible form. At the output of the privacy device, the waves are amplified by both transmitting and receiving privacy repeaters. Any retransmission of these waves from the local transmitter is prevented by relay 4 which is now released. At the output of the receiving privacy repeater the waves pass through the second repeating coil combination and thence to the receiving delay circuit. A part of these waves, if they are strong enough, may operate the receiving detector and thus, relay 3.

After passing through the receiving delay circuit the speech waves travel on through a receiving potentiometer, receiving repeater, hybrid set, and to the subscriber at *A*.

A small part of these waves may be reflected due to the difference in impedance between the subscriber's line and the network and return over the transmitting branch of the circuit. However, if these waves are strong enough to operate relay 3, they are prevented from operating the transmitting relays. If they are too weak to operate relay 3, an adjustment of receiving volume is made so that they will be too weak to operate the transmitting relays. This adjustment is accomplished by the potentiometer ahead of the receiving repeater. The waves are prevented from passing through the privacy device by relay 1 which is released.

In practice, it is necessary to protect the vodas against operation from noise. This is done by frequency discrimination as well as by amplitude discrimination and the use of artificial delay. The detectors have their input circuits arranged to keep out frequencies that are not essential for speech operation. In addition, their sensitivity is made adjustable. The transmitting detector is generally worked at a value which results in no perceptible loss of intelligibility due to failure of the transmitting relays to operate, at the same time allowing a maximum amount of line noise to be applied without operating the relays falsely. The receiving detector is adjusted frequently by the technical operator so as to obtain the best operation on incoming speech without false

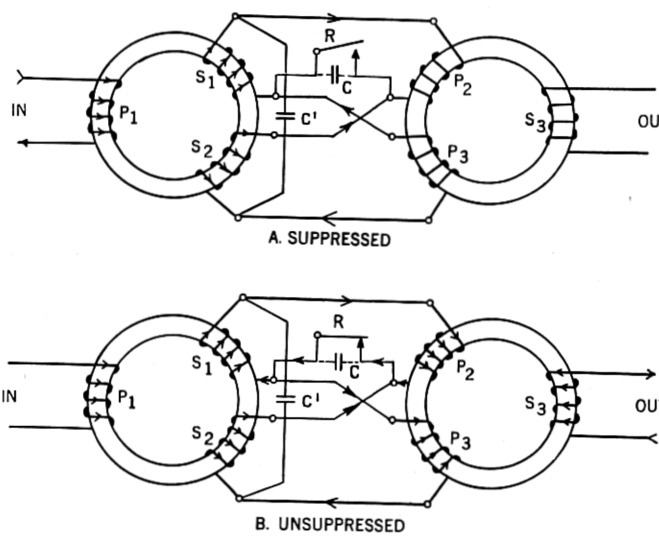

Fig. 3—Repeating coil arrangement for suppressing echoes.

operation from radio noise. When the incoming noise is low, relay 3 may be made very sensitive. Any incoming speech which does not operate relay 3 is thus weak, and the receiving volume may be kept high without danger of echoes operating the transmitting relays. When the noise is high, relay 3 is made insensitive, requiring more loss in the echo path and, consequently, lower volume to the listener.

The method of suppressing transmission by opening a single relay contact is illustrated in detail by Fig. 3. In A of this figure, the relay (R on the figure) is assumed to be operated so that transmission is suppressed. The voltages induced in windings S_1 and S_2 of the first coil are opposed to each other in a circuit including P_2 and P_3 of the second coil, the resulting flux in the core of this coil being very small. Losses

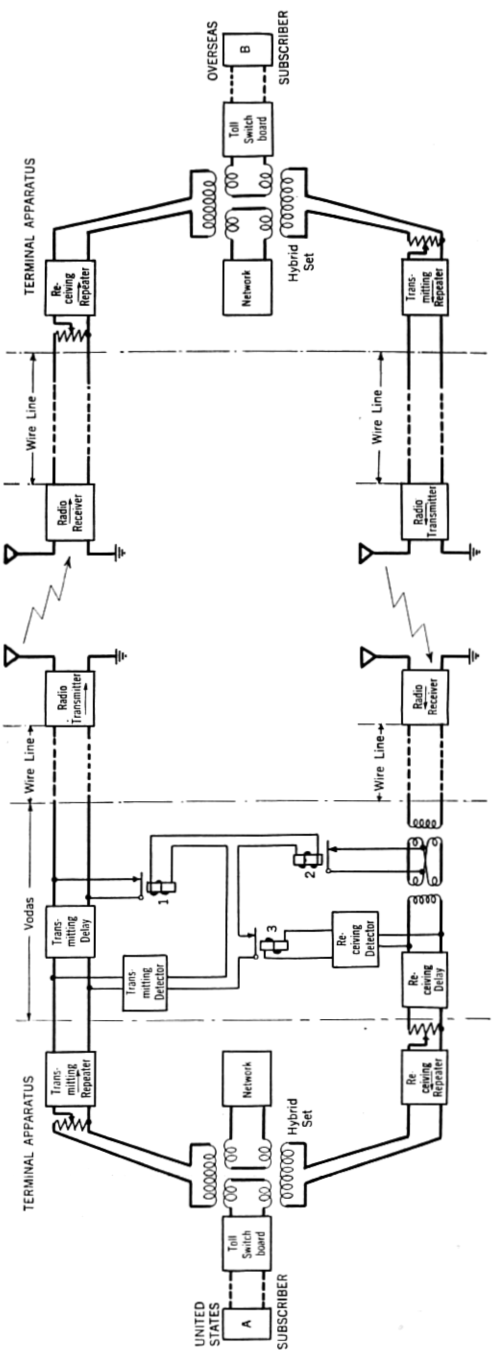

Fig. 4—Radio telephone circuit with vodas at one end only.

as high as 75 db are produced by this arrangement by proper design of coils and adding a small condenser (C') to balance the capacity (C) of the leads to the relay contacts. In practice, a pair of wires is cut off to give the right capacity, and then laced into the cable form. In B of the figure, the circuit is shown in the normal condition. Transmission through the coils is affected only by their normal transition loss. While the windings S_1 and S_2 in A are effectively in series opposing, in B they are connected by separate circuits to the corresponding windings P_2 and P_3, due to the extra path through the relay contact.

Operation of a Radio Telephone Circuit

Having in the vodas a means for suppressing echoes and singing under extreme conditions (with the additional advantages of suppressing intermediate "cross-transmission" paths), it is important to consider the broader application of such a device to radio telephone circuits. Three cases of operation with anti-singing devices are of interest:

1. Vodas at one end, plain hybrid set at the other.
2. Vodas at one end, echo suppressor (without anti-singing relay) at the other.
3. Vodases at both ends.

1. Vodas at One End, Plain Hybrid Set at the Other

This arrangement is shown in Fig. 4. In this and the next figures, the privacy switching circuit has been omitted for simplicity. The vodas prevents singing and echo effects from unbalances at the A end and also prevents the A subscriber from hearing echoes.

The disadvantages of these arrangements may be understood by considering the transmission received at the B end which has no voice-operated relays. Speech received over the circuit would be returned to the local radio transmitter as an echo or echoes. If a weak talker were connected at the B end, the volume control device would amplify these echoes to an appreciable extent. In addition to overloading the radio transmitter, such echo would permit both sides of the conversations to be broadcast from the same station, thus reducing privacy. Radio noise might also be received at B and transmitted as echoes to the A end of the circuit. In addition, line noise from a two-wire circuit at the B end would be freely transmitted to the A end, causing a limitation of the sensitivity of relay 3 and consequently a reduction of volume at the A end.

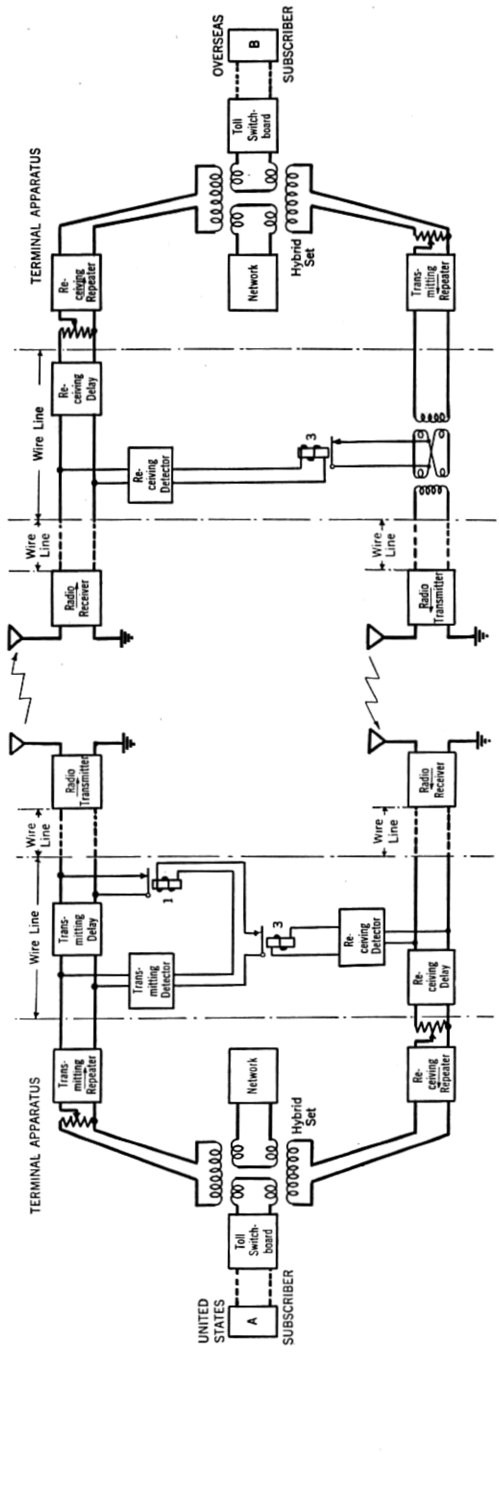

Fig. 5—Radio telephone circuit with vodas at one end and echo suppressor at opposite end.

2. Vodas at One End, Echo Suppressor at the Other

The above possibilities of transmitter overloading and speech reradiation due to echoes might be prevented by adding a voice-operated echo suppressor at the *B* end as shown in Fig. 5. This device would be operated by received speech so as to disable the transmitting branch of the circuit. Its sensitivity would be limited as would also the received volume at one or both ends. It should be noted that if no cross transmission paths existed, relay 2 of the vodas at the *A* end could be omitted when this device is used.

The echo suppressor would not suppress echoes of radio noise or direct transmission of line noise from the *B* end to the receiving relay 3 at the *A* end. Relay 3 would therefore need to have its sensitivity reduced so as not to be operated by these noises. This gives rise to an additional limitation of received volume at the *A* end. The amount of the penalty would, of course, depend on the noise conditions, the talker volume and the echoes in two-wire circuits at the *B* end. Under extreme conditions, the necessary reduction in receiving volume at the *A* end might be as much as 25 db. This is considered to be an important disadvantage inasmuch as conditions at the two ends are not independent and lack of an anti-singing device at one end penalizes the received volume at the other.

Another solution would be to limit the transmitting gain at the *B* end so that the noise transmitted past the echo suppressor would never limit the sensitivity of relay 3 at the *A* end. This would mean that the received signal-to-noise ratio at the *A* end would be reduced, particularly if the taker at the *B* end were weak.

3. Vodases at Both Ends

To summarize, it may be said that anything short of anti-singing devices at both ends does not make the two ends of the circuit independent and may penalize the transmission at the vodas end when there is radio noise or line noise at the end without an anti-singing device. The preferred arrangement is shown in Fig. 6.

Results of Vodas Operation

In general, the results of operation with the vodas have been good and, when radio conditions are favorable, the circuits are not appreciably different from land circuits of comparable length.

Occasionally, the vodases introduce minor difficulties. False operation by noise and simultaneous talking by the two subscribers both tend to cause speech mutilation. The large transmission advantages

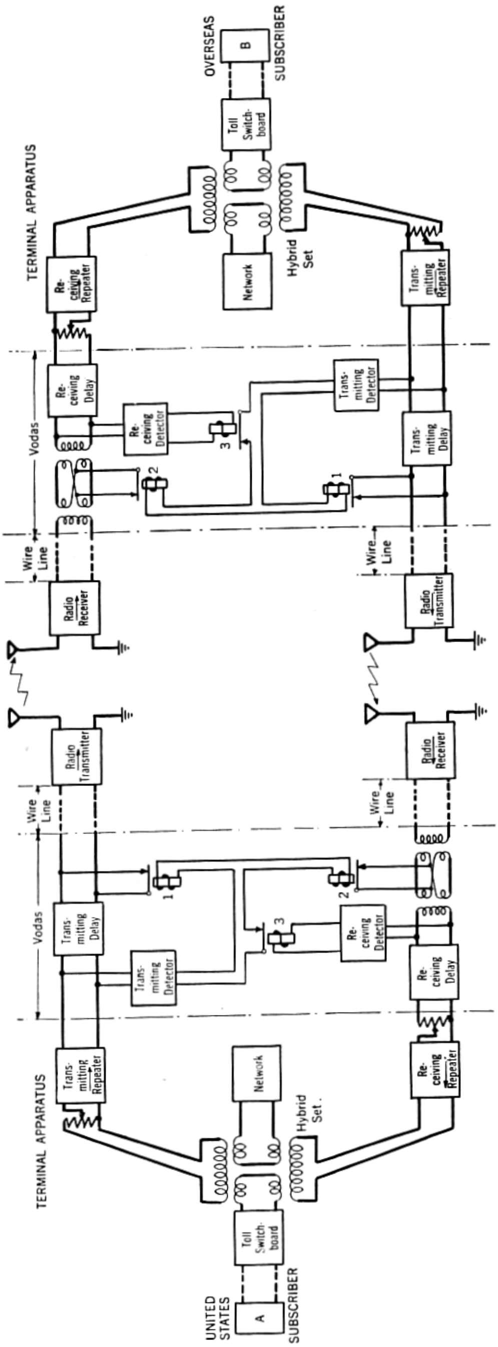

Fig. 6—Radio telephone circuit with vodases at both ends.

afforded by their use greatly outweigh any such troubles. These advantages may be summarized as follows:

1. Suppress echoes and singing which would otherwise be heard due to adjustments to reduce radio noise, instability and cross-transmission paths.

2. Prevent retransmission of echoes which would cause overloading and two-way broadcasting at the radio transmitters.

3. Save privacy apparatus.

4. Permit the telephone listeners to hear louder speech waves.

5. Afford independent technical operation of the two ends of the circuit.