# Neutralization of Telegraph Crossfire

By R. B. SHANCK

SYNOPSIS: With the simple means here described for neutralizing mutual interference between parallel telegraph circuits, it has been found practicable to effect a reduction to 10 or 20 per cent of the original values. This has improved considerably the operation of some circuits and made available others which were previously unsuitable. The resulting improvement in transmission has made possible the elimination of certain intermediate telegraph repeaters with material savings. The neutralizing apparatus has no material effect when crossfire is not present, that is, when the paralleling wires are idle. It has been found that the use of arrangements here described on certain long open wire circuits makes possible fast manual full-duplex operation where only medium-speed half-duplex operation was possible before. Furthermore, in the case of some cable circuits where it was impossible to operate more than two telegraph circuits per quad, it is now practicable to obtain four telegraph circuits.

## INTRODUCTORY

MANY ground-return telegraph circuits are subject to serious mutual interference due to their proximity to one another on pole lines or in cable and in certain cases due to interconnection in office apparatus. The interfering currents, commonly referred to as "crossfire", in one telegraph circuit, caused by the transmission of signals on paralleling telegraph circuits, have caused considerable difficulty in the operation of such circuits. Crossfire has either limited the speed of operation or seriously impaired the quality of transmission in many cases.

In the following there are described methods which have been successfully applied to a number of ground-return polar-duplex telegraph circuits in the Bell System for the purpose of neutralizing crossfire. These arrangements are comparatively inexpensive and afford a marked improvement in transmission. This paper deals specifically with methods for use on wires which are either used simultaneously for telephone purposes or at least are grouped and transposed so as to be suitable for telephone operation; there is, however, no reason why the principles may not be profitably applied in many cases where wires are intended exclusively for telegraph use.

## NATURE OF CROSSFIRE

When mutual admittance, or coupling, exists between two telegraph circuits, operation of one, of course, occasions extraneous current impulses in the other circuit. The presence of such impulses in the receiving apparatus at the terminals of the disturbed circuit results in adverse effects on the telegraph signals. In the case of closely parallel circuits extending between two stations, considerable interference is generally experienced both at the station from which the disturbing signal is transmitted and also at the distant station. In this paper, the crossfire current (noted in the interfered—with circuit) at the station from which the interfering signal is sent will be referred to as "sending-end crossfire" and that at the distant station as "receiving-end crossfire". For example, assume two parallel wires from A to B; if a signal be sent on wire No. 1 from A to B, sending-end and receiving-end crossfire will appear in the receiving apparatus of wire No. 2 at A and B, respectively. This may mutilate incoming signals, or in extreme cases cause false signals.

The type of line circuit and the kind of apparatus employed have a considerable effect upon the amount of crossfire between circuits. It has been found that it depends chiefly upon the amount of mutual capacitance and, to a lesser extent, upon the natural mutual inductance of the wires; mutual conductance or leakage is responsible for some d-c. crossfire during periods of low insulation resistance but this increment is in general comparatively unimportant. As will be brought out later, loading[1] of circuits has a large effect on crossfire. Such factors as the gauge of wire, separation between wires, length of circuit and the presence of other wires on the same pole line have, of course, considerable influence.

In the Bell System plant, crossfire is in general of little consequence except among the four wires of a "phantom" group, the reasons for which will be discussed later. It is of interest to note that receiving-end crossfire is comparatively much more serious between wires in cable than between those of open-wire lines. Entrance cable, that is, cable employed to bring open-wire circuits into large cities, has comparatively little effect, as the length is generally short. Such apparatus as the composite sets which are used to derive d-c. telegraph circuits from telephone wires, and in certain cases filters used in connection with superposed carrier-current systems, contribute to crossfire inasmuch as they introduce some coupling, chiefly mutual capacitance.

Fig. 1 shows schematically the circuit arrangement of the polar-duplex telegraph apparatus in conjunction with a pair of wires composited for simultaneous telephone and telegraph operation. These types of apparatus are well known and will therefore be described only briefly. Independent two-way telegraph transmission is possible on each wire since the receiving relay occupies a position in a

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[1] See "Development and Application of Loading for Telephone Circuits", Shaw and Fondiller, A. I. E. E. Jour. March, 1926.

balanced circuit analogous to that of a Wheatstone-bridge galvanometer as regards outgoing signals, and is therefore operated only by incoming signals. The fact that the home relay is not influenced by the home battery will be appreciated by considering the battery at the distant station to be short-circuited and the artificial line to balance the line and distant apparatus perfectly. When battery is introduced at the distant station however it causes a signal to be received at the home station as it corresponds to inserting a battery in one arm of a Wheatstone bridge. The " bridge coil " is connected so as to be series-aiding for incoming signals, the inductance being about 75 henries in this case, and parallel-opposed for outgoing signals, the inductance then being about 3 henries. The composite set serves to separate the telephone currents from those of the two telegraph circuits by " filtering " action or frequency discrimination, the telegraph employing a frequency range below that of the telephone.

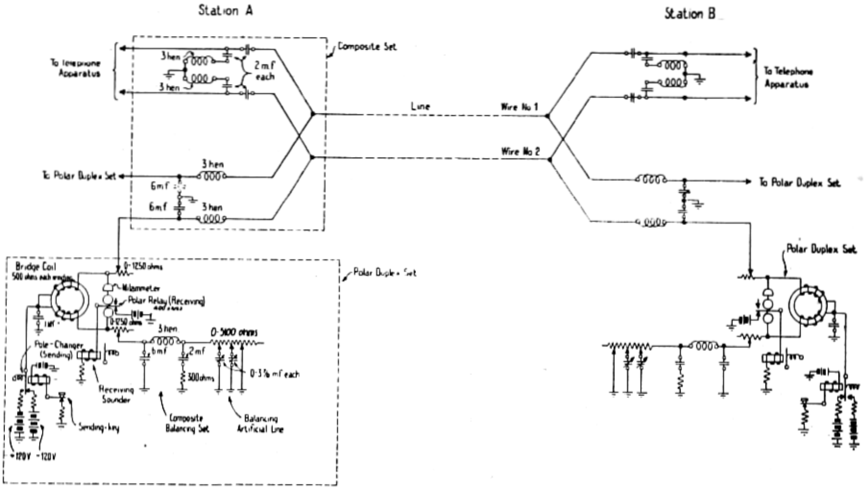

Fig. 1—Line equipped with composite sets and ground-return polar duplex sets

The oscillograms which are shown in Fig. 2 illustrate the wave shape and magnitude of crossfire impulses in comparison with the normal operating currents, in a typical composited large gauge cable circuit. Trace A shows the wave-shape of the normal current in the line at the sending end (reduced to about one-seventh as compared to the other waves), and B shows the current in the receiving relay at the distant station. Although it is not outstanding in the

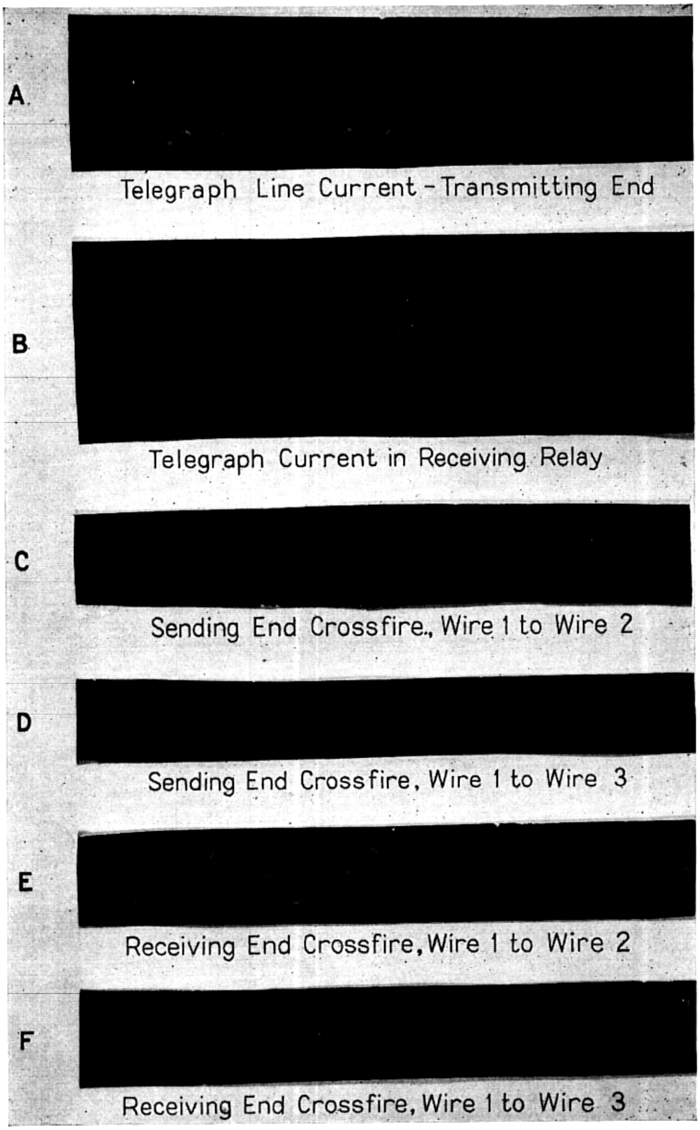

Fig. 2—Telegraph operating and crossfire currents. 13 B.&S. Ga. loaded cable Quad. 90 miles in length

Note 1: Oscillograms of crossfire current taken with vibrator in series with receiving relay

Note 2: Wave "A," 150 milliamperes per inch; other waves 20 milliamperes per inch present instance, the sending-end current is usually characterized by peaks and rapid changes, while the received wave is somewhat rounded off, and this results in most of the induction taking place in the portion of the line near the sending station and the apparatus at that station. C illustrates sending-end crossfire between wires of the same pair and D that between wires of different pairs but in the same quad. Trace E shows the receiving-end crossfire between wires of the same pair and F that between wires of different pairs but in the same quad. C, D, E, and F may be considered as superposed in various combinations on B to obtain an idea of the mutilation of signal waves at usual speeds of manual Morse operation.

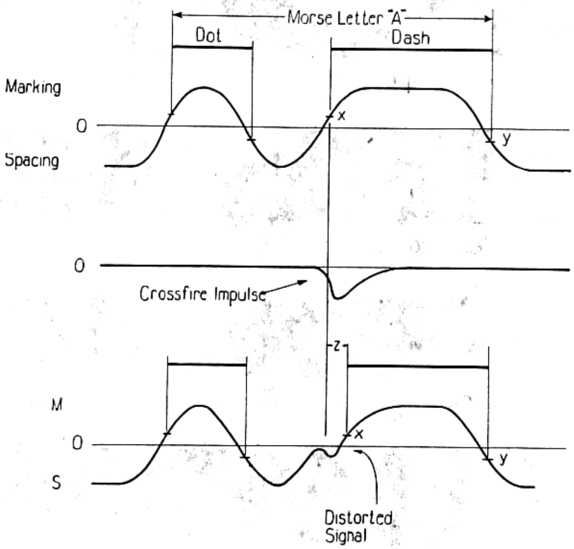

Fig. 3—Distorting effect of crossfire impulse

Fig. 3 has been drawn to illustrate how a crossfire impulse may cause distortion of a telegraph signal. The lowest wave is a combination of the received signal and crossfire impulse which are shown above. X and Y are the points at which the polar relay operates, assuming that it is required that the current build up or down appreciably beyond zero in order to move the armature. It will be clear that the dash has been shortened by the amount Z. Obviously only a limited amount of such distortion is allowable in telegraph signals. Under some conditions the crossfire is of sufficient strength to cause false signals, such as an extraneous dot in a long space or a break (space) in a dash.

An additional serious effect of crossfire is that it interferes with the obtaining of accurate duplex balance adjustment, since crossfire currents mask the effect of small changes in the balancing artificial line.

## PRINCIPLES OF NEUTRALIZING ARRANGEMENTS

The principles involved in neutralizing the crossfire will first be discussed for the simplest case, that is, with only two parallel wires, reserving the case of four wires for the next section of this paper.

### *Sending-end Crossfire*

An arrangement suitable for neutralizing the sending-end crossfire between two polar-duplex circuits is illustrated in Fig. 4. The heavy arrows indicate the disturbing line current which flows when the tongue of the pole-changer of circuit Y at station A moves from the negative to the positive pole. The feathered arrows show the direction of the resulting crossfire currents which tend to flow through the polar relays of circuit X. It will be apparent that the sudden increase, in a positive direction, of the potential applied to circuit Y would cause an impulse of current in the relay of X at the sending station A in the direction shown if the circuits were coupled by capacity only or by the natural mutual inductance of the two parallel ground-return circuits. Neutralization is effected by providing a mutual admittance between the two balancing artificial lines to simulate that existing between the real lines. It will be clear that upon the operation of the pole-changer of circuit Y, an impulse will pass through the neutralizing circuit C, R, and through the relay of circuit X at A in such direction as to oppose the crossfire current.

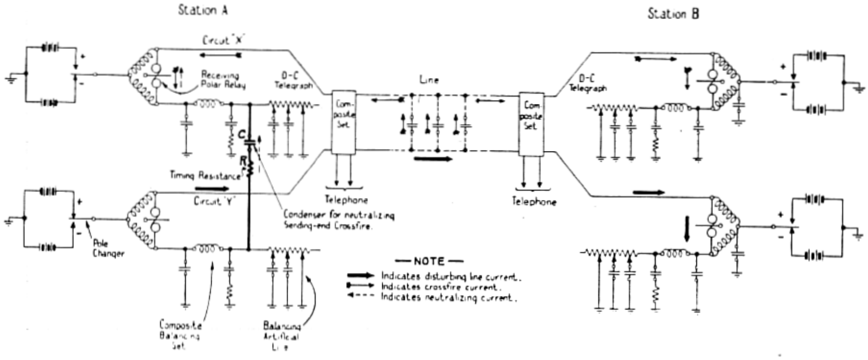

Fig. 4—Method of neutralizing sending-end crossfire between two telegraph circuits

(The neutralizing impulse is indicated by the dotted arrows.) Another point of view is that a symmetrical or balanced arrangement similar to a Wheatstone bridge is provided in which the coupling of the line circuits is balanced by the coupling introduced between the artificial lines. It has been found experimentally that a simple connection consisting of a condenser and a timing resistance in series as shown are sufficient to effect neutralization on either open-wire or cable circuits. It will, of course, be seen that such a connection is effective for neutralizing crossfire from either circuit into the other, and furthermore that it is capable of performing both functions simultaneously.

As shown in Fig. 4 the neutralizing connection is made at the beginning of the artificial line (at the junction of it and the composite balancing set). This is a convenient point and has been found satisfactory for the purpose.

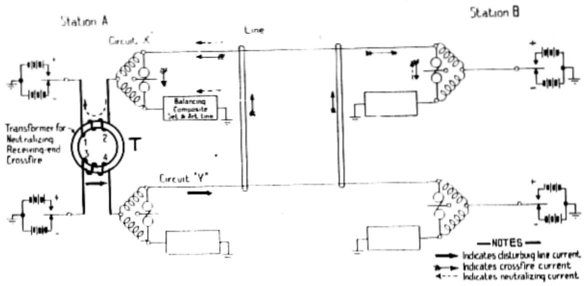

Fig. 5—Method of neutralizing receiving-end crossfire between two telegraph circuits

Condenser arrangements have been in use in this country and abroad for some years in various ways for neutralizing sending-end crossfire on both land lines and short submarine cables.

### *Receiving-end Crossfire*

For neutralizing receiving-end crossfire use is made of special connections at the sending end. The method consists in impressing a neutralizing impulse on the disturbed circuit at the sending station, in such manner as not to affect incoming signals at that station, (that is, it does not introduce sending-end crossfire); the neutralizing impulse will then travel along the interfered-with circuit so as to arrive at the distant station at the time when the crossfire impulse appears at that station.

The operation of the receiving-end crossfire neutralizing apparatus will be made clear by reference to Fig. 5, in which the heavy arrows indicate the disturbing current, the feathered arrows the crossfire current and the dotted arrows the neutralizing current. The last mentioned current is impressed upon the disturbed circuit X by means of a transformer connection (T) between the "apex" or transmitter branches of the two circuits. It will be obvious that if a good duplex balance has been obtained the neutralizing impulse will divide practically equally between the real and artificial lines of circuit X and substantially none of it will pass through the receiving polar relay of circuit X, on account of the balanced bridge arrangement. It will therefore have no effect on signals received at A, but will generate neutralizing impulses which will travel over X to B so as to appear at B at the same time as the crossfire currents. It has been found possible to employ coupling such that the receiving-end crossfire is practically eliminated in the polar relay. The proper poling of the neutralizing transformer has been found to be as indicated in Fig. 5 for all types of circuit to which the device has been applied. The crossfire impulse has the direction shown, for the reason that capacity coupling predominates.

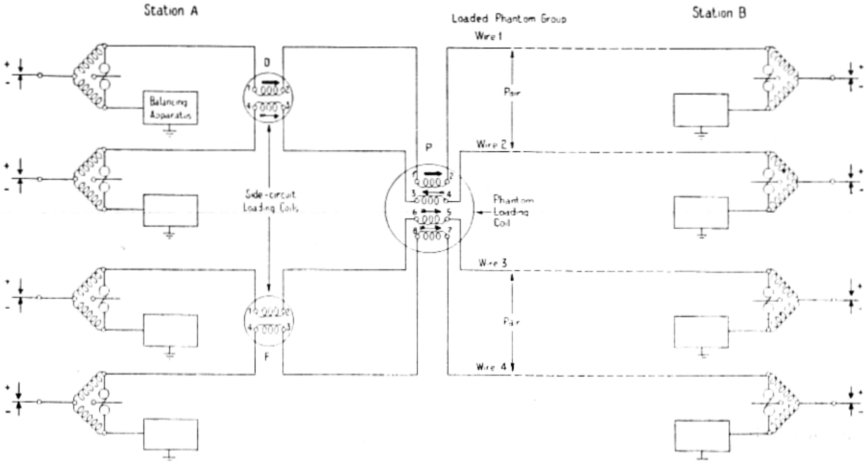

Fig. 6—Effect of loading coils on crossfire

Note: → Signalling Current ➧→ Induced Current

## LINE CHARACTERISTICS

The first part of this section will be devoted to a discussion of the effect of loading and line transpositions. This will show why, in the telephone plant, it is necessary to deal with crossfire among the four wires of a phantom group only. Then arrangements for use with a group of four wires employing the principles explained above in connection with the case of two parallel wires, will be covered.

It is of interest to consider the effect of the loading coils which are employed in conjunction with many telephone lines.[2] In Fig. 6, coils D and F represent side-circuit loading coils on pairs 1–2 and 3–4, respectively, and P a phantom-circuit loading coil. Such coils are connected into telephone circuits at intervals to introduce inductance into the two telephone side circuits and the phantom telephone circuit, respectively.

The action of the side-circuit coil, (D), will first be considered. If a positive telegraph impulse is sent from A to B over wire 1, as indicated by the heavy arrow, it is evident that the coil acting as a transformer will set up a crossfire current in wire 2 in the same geographical direction, as indicated by the feathered arrow. The relation of this impulse to those due to capacity coupling is of interest since the capacity effect predominates. Comparison with Fig. 5, will show that at the transmitting station the impulse due to coil D will oppose the sending-end crossfire which is due to capacity coupling between circuits, while at the distant end it will augment the receiving-end crossfire due to capacity coupling. Coil F functions similarly in pair 3–4.

In the case of the phantom loading coil (P) sending an impulse from A to B on wire 1 results in disturbing currents in the same geographical direction in wires 3 and 4 and in the opposite direction in wire 2, since the coil is connected so that two windings are series-opposed in each side circuit and parallel-aiding in the phantom circuit. Comparing with Fig. 5, as before, it will be seen that for wires of a group but not of the same pair these coils tend to neutralize the sending-end crossfire which is due to mutual capacitance and augment the receiving-end crossfire due to capacity coupling; the conditions will be reversed however for wires of the same pair.

In the case of loaded circuits, crossfire, therefore, is due to loading as well as to the mutual capacitance and inductance of the wires and the coupling which exists in office apparatus, so that the final result is difficult to predict. Work with loaded circuits, which has been largely confined to cables indicates that on such circuits receiving-end crossfire is generally greater than sending-end crossfire, and sending-end crossfire between wires which are in the same phantom group but not in the same pair is so small as to be almost negligible.

Line transposition of telephone circuits has been discussed at

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[2] Shaw and Fondiller, loc. cit.

considerable length in a previous paper.[3] Such transpositions consist in interchanging systematically the pin positions of the two wires of a pair and of the wires of the two pairs comprising a phantom circuit. It should be clearly understood that while these transpositions are effective in balancing a two-wire or metallic circuit against other circuits, they cannot be used to balance ground-return circuits (such as the telegraph circuits in question) against each other; however, their effect in varying the separation of the different wires from each other has a great influence on the coupling between the ground-return circuits.

A possible transposition section for an open-wire phantom group is shown in Fig. 7. It will be seen that the two wires of a pair are always adjacent to each other and will therefore have considerable coupling; a wire of one pair is adjacent to a particular wire of the other pair for only one-fourth of the distance, and wires of the two pairs will therefore have much less coupling.

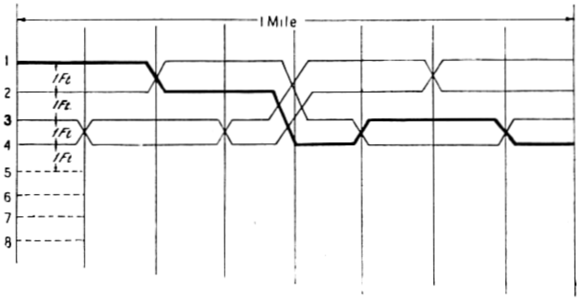

Fig. 7—Line transpositions of open-wire phantom group

A brief consideration will make it clear that coupling between wires of separate phantom groups is comparatively small. Each wire of the group 1 to 4 occupies pin position 4 only one-fourth of the distance, and if 5 to 8 be phantomed each wire of the latter group will use pin position 5 one-fourth of the distance. It follows that a wire of group 1 to 4 will be adjacent to a particular wire of group 5 to 8 only one-sixteenth of the distance in a long circuit. If 5-6 be non-phantomed however each wire of the pair will use position 5 half of the time and will be adjacent to each wire of 1 to 4 one-eighth of the way. The next crossarms above and below are each two feet distant and carry wires transposed so as to minimize the coupling.

[3] "The Design of Transpositions for Parallel Power and Telephone Circuits," H. S. Osborne, Proc. A. I. E. E. 1918, Vol. XXXVII p. 739.

It should be noted that in addition to the reduction in coupling due to increasing the spacing there is a large reduction due to shielding when a third conductor is interposed between two others.

In the case of cable circuits the wires are twisted in groups of four so as to be transposed practically continuously. On account of the smaller separation, mutual capacitances and the resulting crossfire among wires of a phantom group, are considerably greater than in open wire.

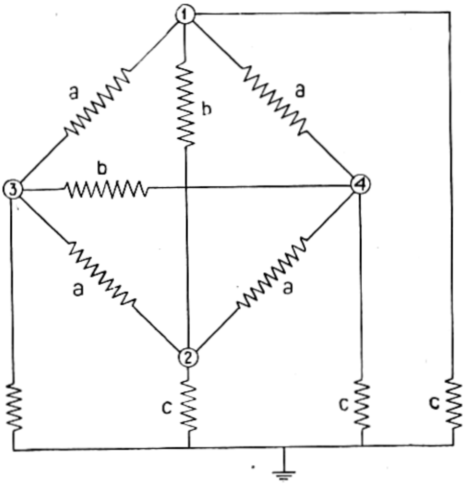

Fig. 8—Admittance Network

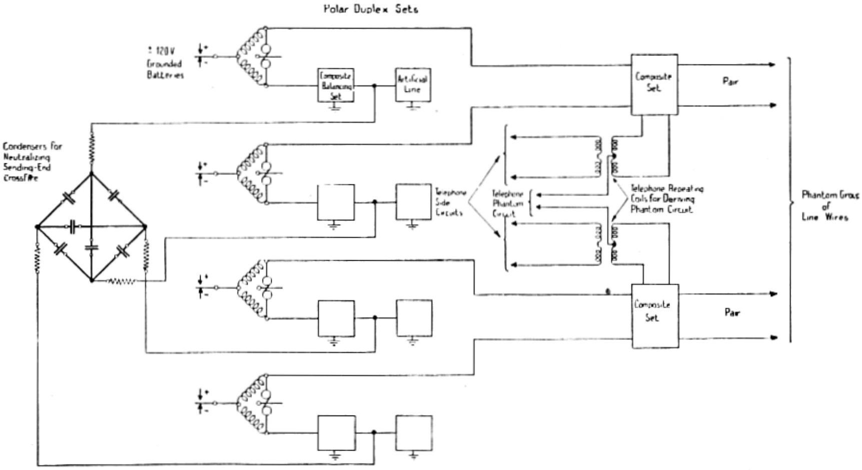

Fig. 9—Condenser arrangement for neutralizing sending-end crossfire between telegraph circuits on a phantom group

The result of transposing is that for practical purposes in connection with the crossfire problem the other wires of the line can be ignored and a phantom group represented by a network of admittances as shown in Fig. 8, where 1 and 2 represent a pair and 3 and 4 the other pair.

A network of the form of Fig. 8, is used as shown in Fig. 9, for neutralizing sending-end crossfire among the four wires of a phantom group. The grounded branches shown in Fig. 8 are omitted, however, since the duplex artificial lines themselves constitute these branches. The six-mesh network consists of condensers, the timing resistances when used being external to the network as a matter of convenience.

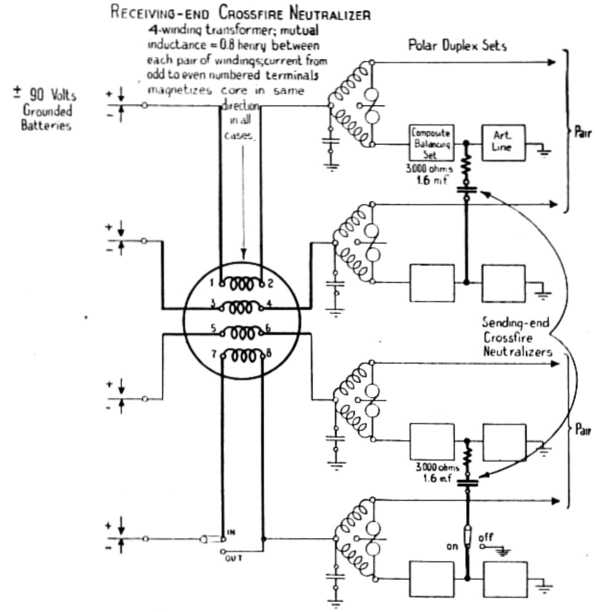

Fig. 10—Arrangement for neutralizing crossfire between telegraph circuits on a loaded No. 13 B.&S. Ga. phantom group 90 to 120 miles long in cable

For coupling together the apex circuits of the four wires to neutralize receiving-end crossfire, it is possible to use a special four-winding transformer analogous to the six-condenser network, but where an ordinary transformer as shown in Fig. 10 will not suffice it is convenient to employ two or three transformers in combination. For example a two-winding transformer may be added to each pair of the arrangement illustrated in Fig. 10 so as to provide additional coupling between the two wires of a pair.

It will readily be seen that with neutralizers applied at each end of the four circuits, transmission of signals on one of them will generate the proper impulses for neutralizing both sending and receiving-end crossfire from that circuit into the other three. Furthermore, neutralization will take place with all wires operating simultaneously in either or both directions.

## Application to Different Circuits

It is in general not practicable to compute the constants of the neutralizing devices, but this is unnecessary since it is an easy matter to determine them experimentally. In making trials to determine the proper amount of capacity and inductance required to neutralize crossfire effectively, it is fortunately possible to design the various parts independently of each other to a considerable extent. For example, the diagonals of the six-condenser network may be determined after the condensers in the sides have been approximated very roughly, or vice-versa; likewise, the amount of inductance required between each pair of circuits may be approximated independently, but if a single coil is to be used for coupling more than two circuits, all the circuits should be connected up in making the test. Sending and receiving-end crossfire may, of course, be treated separately.

It is convenient to vary the capacity of the condensers, but not usually the inductance of the transformer. In the latter case a coil with excess mutual inductance may be used together with a variable resistance shunt.

In order to design neutralizing arrangements or to determine whether or not they are effective, tests may readily be made by observing the deflection of a milliammeter connected in series with the polar relay of a bridge polar-duplex set while signals are sent on the parallel circuit. In a similar way a differential meter may be used in a differential duplex set. A somewhat more accurate test may be made by observing the response of the receiving relay, preferably with variable electrical bias. The disturbing signals are of course sent from the same station in checking sending-end crossfire and from the distant station in checking receiving-end crossfire.

Representative anti-crossfire capacity values are given in the following table for No. 8 B.W.G. (0.165 in., 2.5 mm.) composited open-wire copper circuits, 300 to 500 miles (500 to 800 km.) in length and No. 12 A.W.G. (0.104 in., 1.5 mm.) circuits 150 to 300 miles (250-550 km.) in length. No timing resistance is required usually. In practice there are material variations from one circuit to another.

| Gauge | Loading | Non-Phantomed Pair | Phantom Group Network[4]<br>Diagonals | <br>Sides |
|---|---|---|---|---|
| 8 | Non-loaded | 1.7 mf. | 1.7 mf. | 1.2 mf. |
| 8 | Loaded | 1.1 " | 1.1 " | 0.55 " |
| 12 | Non-loaded | 1.1 " | 1.1 " | 0.8 " |
| 12 | Loaded | 0.8 " | 0.8 " | 0.4 " |

The superposition of carrier-current channels by means of filters connected on the drop side of the d-c. composite set of course has no appreciable effect on crossfire. However, the use of "transfer filters" at intermediate points to transfer the carrier from one pair to another increases the coupling between wires of a pair and this may be taken care of by increasing the capacity of the diagonals of the condenser network.

The arrangement shown in Fig. 10 has been found to be suitable for use with 90 to 120 mile (145 to 190 km.) sections of No. 13 B.&S. gauge (0.072 in., 1.8 mm.) loaded cable circuits.

In the case of open-wire circuits, receiving-end crossfire is commonly not serious excepting in special cases where high-frequency carrier telephone or telegraph transfer filters are employed. In such cases, effective neutralization may be secured by coupling the wires of each pair by means of a transformer, no such coupling being provided between the wires of separate pairs of a phantom group.

In some cases the neutralizing arrangements and the telegraph repeaters have been wired to jacks in such a manner that it is possible to patch the neutralizers from set to set by means of cords when the line assignment is changed temporarily. In some cases it is not desirable to provide such elaborate arrangements and, therefore, switches are provided for disconnecting the neutralizing apparatus from each set independently. In the case of the condensers, the duplex balance of the other telegraph sets associated with the particular group of condensers is preserved by switching directly to ground the connection from the artificial line of the set to be disconnected, as shown in conjunction with the lowermost duplex set in Fig. 10. Switches for disconnecting the neutralizing transformers are illustrated also for the same duplex set in this figure.

## PRACTICAL RESULTS OBTAINED WITH NEUTRALIZATION

The following table gives data which show roughly the amount of crossfire between wires of a phantom group without neutralizing

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[4] See Figure 9.

arrangements for various circuit conditions. It will be noted that crossfire between a pair of wires used for a telephone side circuit is considerably greater than that between wires of a phantom group but not of the same pair. This is in accord with what was brought out above regarding coupling. The receiving-end crossfire is much greater between cable circuits than in the case of open wires, due to the greater mutual capacitance and heavier loading.

CROSSFIRE CURRENT IN PER CENT. OF OPERATING DIRECT-CURRENT

For Average Repeater Sections

| Type of Circuit | Sending End | | Receiving End | |
|---|---|---|---|---|
| | From Other Wire of Pair | From Wire Of Other Pair | From Other Wire of Pair | From Wire Of Other Pair |
| Non-loaded Open Wire.............. | 20 | 10 | 10 | 5 |
| Loaded Open Wire. | 10 | 5 | 5 | 5 |
| 13 B.&S.Ga. Loaded Cable............. | 20 | 5 | 30 | 25 |

It is practicable to reduce the crossfire to 10 or 20 per cent. of the original value by means of the arrangements which have been described. This has improved considerably the operation of some circuits and made available others which were unsuitable for use. By improving transmission so as to avoid the use of intermediate telegraph repeaters material savings have been effected in certain cases.

The neutralizing apparatus has no material effect on the quality of telegraph transmission obtained when crossfire is not present, that is, with the parallel wires idle; the application of them, however, reduces greatly the detrimental effect of crossfire on transmission. For example, the use of these arrangements on certain long open-wire circuits makes possible fast manual full-duplex (two-way) operation where only medium-speed half-duplex (one-way) operation was possible before. Furthermore, in the case of some cable circuits where it was previously impossible to operate more than two telegraph circuits per group of four wires, it is now practicable to obtain four telegraph circuits per quad.

Due to reduction of crossfire, it is usually possible to secure a much better duplex balance after the neutralizers have been applied. The application of anti-crossfire condensers however requires that a somewhat different setting of the duplex artificial line be obtained for the best balance, since the extra connection has appreciable admittance to ground.