TELEGRAPH CIRCUITS (INLAND)

CONTENTS

INTRODUCTION

In telegraph working two systems of signalling can be used; either the single-current or the double-current method. The single-current method has been abandoned by the P.O. in favour of double-current working using teleprinters.

The single-current system

In the single current system only one signalling battery is used. For example the letter 'A' in the morse code consists of a dot followed by a dash, which can be represented on a diagram as shown in Fig. 1, using the single current system.

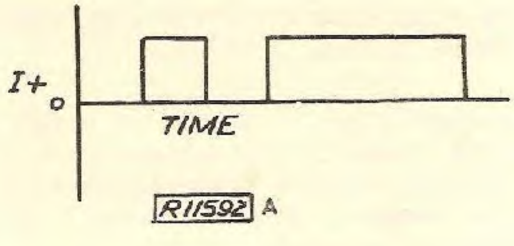

Fig. 1

During the space interval between the dot and the dash, there is no current flow in the line. If the circuit is long the line will have appreciable capacitance and will take a significant time to charge and discharge. The effect of this is to lengthen the signals which tends to slow down the rate at which signals may be transmitted. Double-current working overcomes this difficulty.

Double-current working

Double-current working makes use of two batteries for signalling purposes. Fig. 2 represents the letter 'A' in morse code using the double current system.

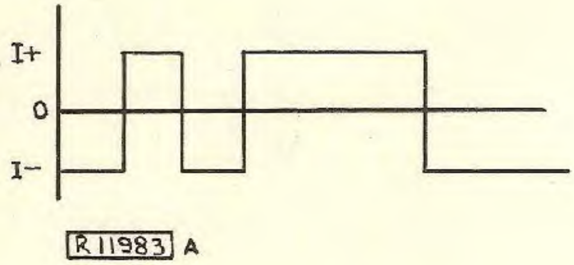

Fig. 2

It will be seen that instead of the spacing interval between signals consisting of a period of no current, it consists of a reverse current. The effect of this reverse current after every signal is to hasten the discharge of the line and so enable signalling to proceed at a greater speed.

Simplex and Duplex working

Telegraph circuits may be divided into two general types viz. simplex and duplex. On a simplex circuit signals may be transmitted in one direction only at a given time, whereas with duplex working simultaneous transmission in opposite directions over a single circuit is possible.

SIMPLEX

Simplex circuits may be used for either single or double-current signalling. Single and double-current simplex circuits are shown in Fig. 3 (a) and (b).

The operation of the circuits is self-explanatory, but it should be noted that a send-receive switch is used to connect either the transmitting mechanism or receiving electromagnet to line as required. If simultaneous communication is required in both directions and simplex working is desired, then a two way simplex circuit of either single or double-current working may be used.

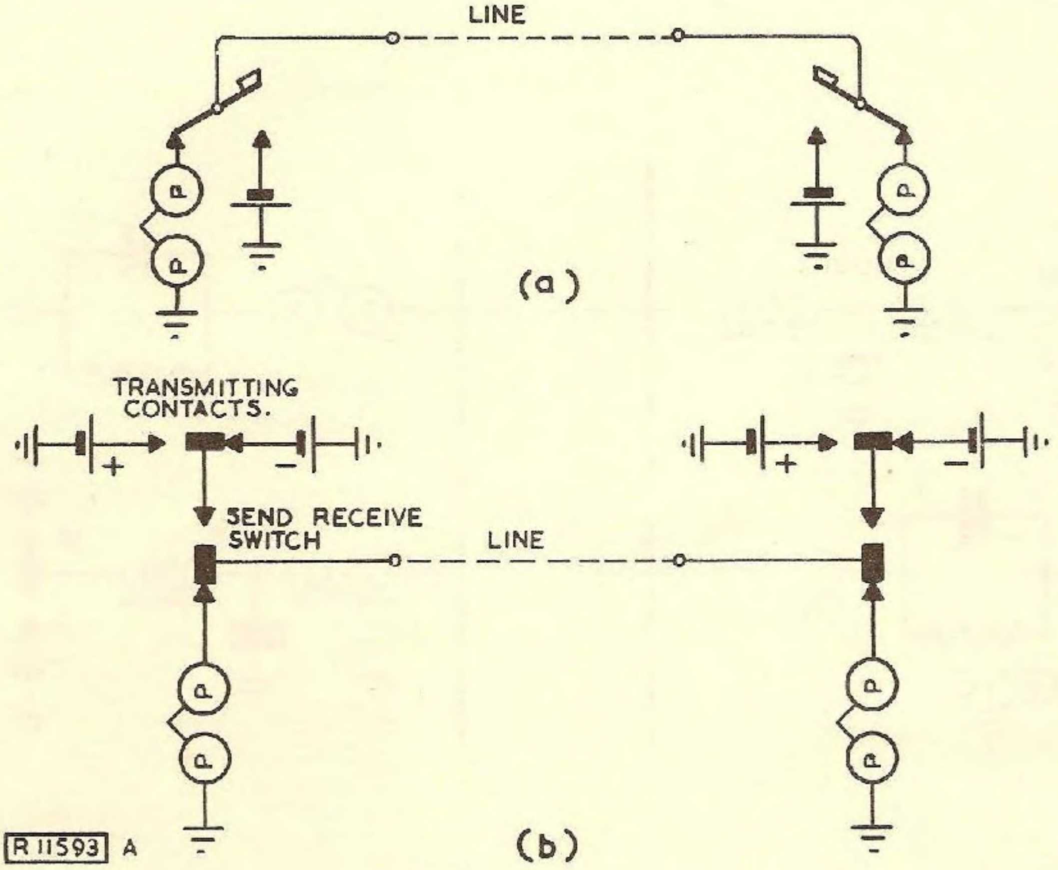

Fig. 3

2-way simplex circuit

In the circuit shown in Fig. 4, a filter is included in the line side of each transmitting circuit to minimize the interference to telephone circuits in the same cable by attenuating the higher harmonics of the telegraph signals.

The function of the shunted capacitor connected in series with the electro-magnet is explained in the pamphlet on telegraph theory. The value of the resistor is such that it will limit the line current to 15 mA.

This type of working is suitable for use on underground lines up to about 40 miles long. Above this figure interference between circuits is liable to take place because the lines are unbalanced. In this circumstance the earth returns are replaced by conductors, and loops are used in both directions.

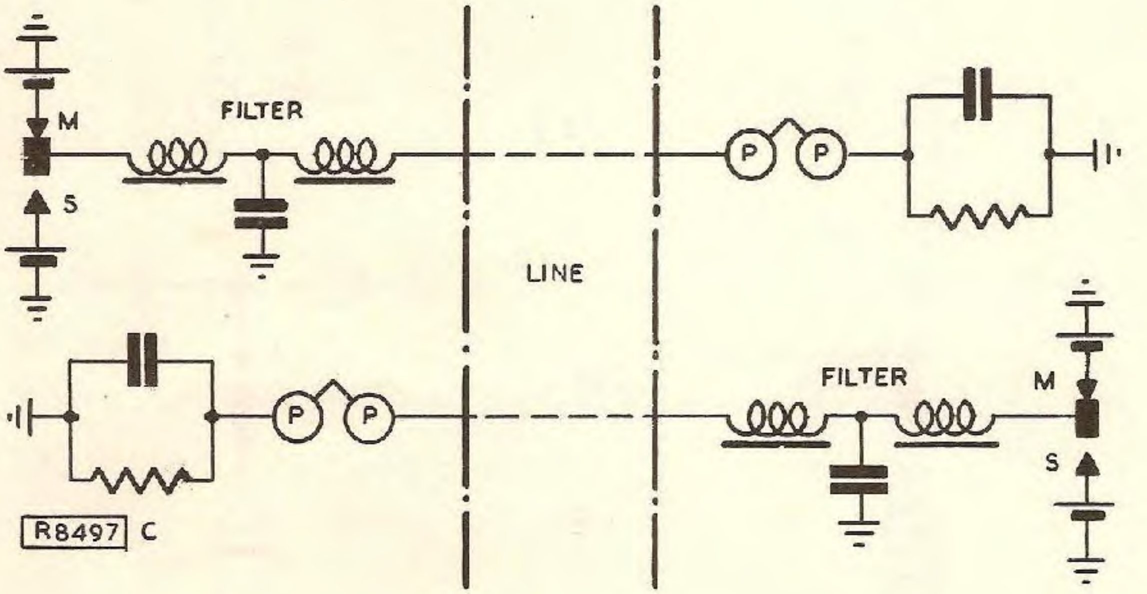

Fig. 4

Two-line simplex circuit using a common battery

This circuit, illustrated in Fig. 5 is designed to avoid the necessity of providing battery power at the out office.

The negative side of the earthed battery is fed via a polarized relay RR to the B wire which is terminated on the transmitting tongue of the out office teleprinter. The relay RR has a spacing bias, but is held to mark by the current which flows via the B wire and the mark contact of the transmitting tongue, when the tongue is in its normal position. The spacing contact at the out station is normally disconnected, and when the transmitting tongue moves to spacing the battery is disconnected and the bias moves the tongue to spacing. The teleprinter electromagnet at the head office is connected to the tongue of the receiving relay and receives pulses of current from the earthed batteries connected to the relay contacts. Transmission from the out station to the head office is therefore single current. The head office transmits double-current pulses to the A wire and thence via the out station electromagnet to earth.

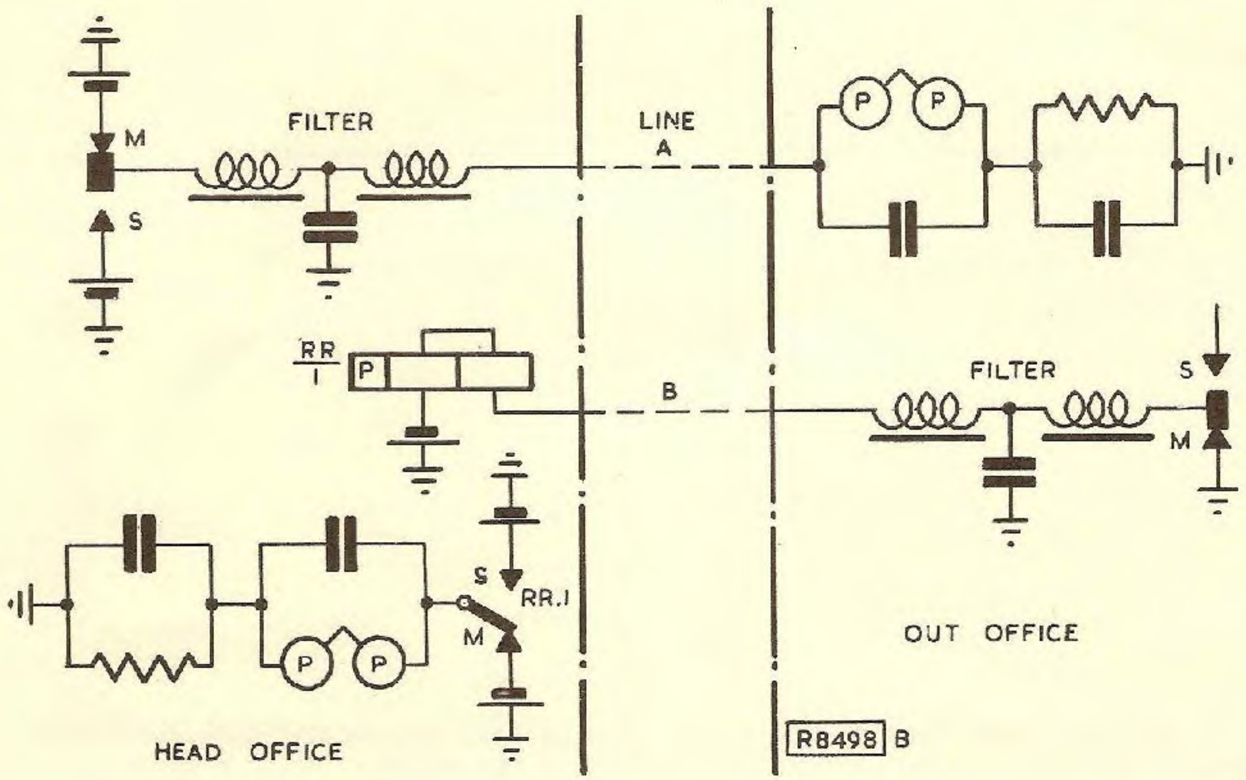

Fig. 5

DUPLEX

There are two methods of duplex working, differential and bridge. The former is adopted for all inland circuits while the latter is used for submarine cable circuits. Single and double-current signalling can be employed in both systems. In the differential duplex system there are again two methods of working, the combination method and the opposition method. Teleprinter working, which has superseded all other methods for inland circuits, is worked upon the double-current opposition method and this will be considered in detail.

In order to obtain duplex transmission the following conditions must be fulfilled:-

(1) The relays at both ends of the circuit must be held to marking when both transmitting tongues rest upon the marking contacts.

(2) When the transmitting tongue at A is moved to spacing, the relay tongue at B must move to spacing while at A the relay tongue must remain at marking.

(3) When both transmitting tongues are at spacing both relays must be operated to spacing.

Before describing the action of a duplex circuit it is necessary to consider the effects of current in the differentially connected coils of a polarized relay, such as the carpenter relay (see E.P. GEN. 3/4). Consider Fig. 6.

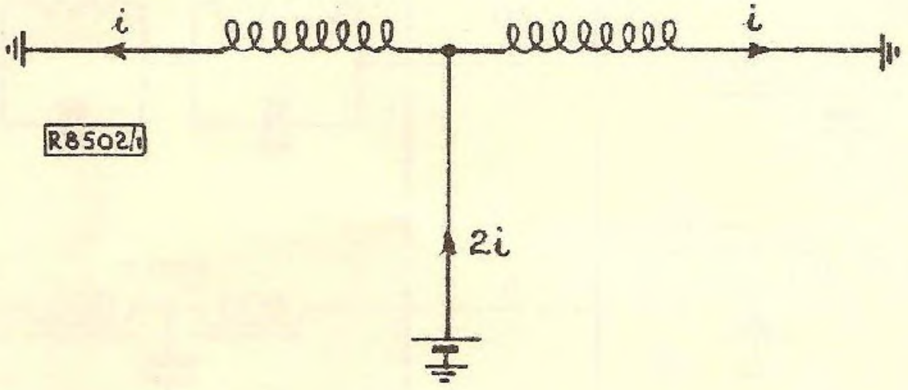

Fig. 6

Here equal currents flow through the two relay windings, but in opposite directions. Consequently they have no effect on the armature of the relay. Fig. 7 shows a similar circuit where the balance network is electrically identical to the line and receiving equipment, hence the current divides equally and the relay does not operate.

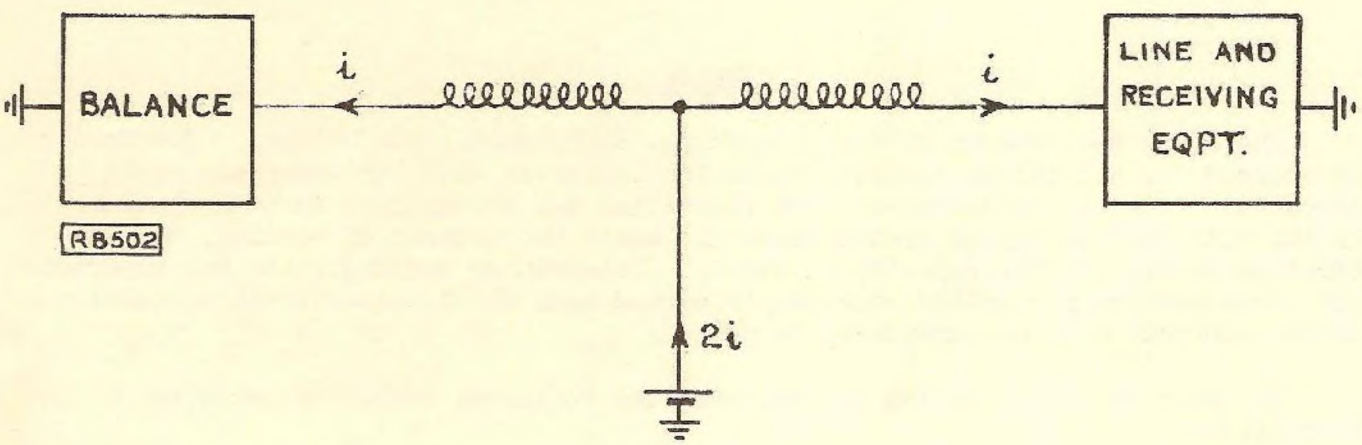

Fig. 7

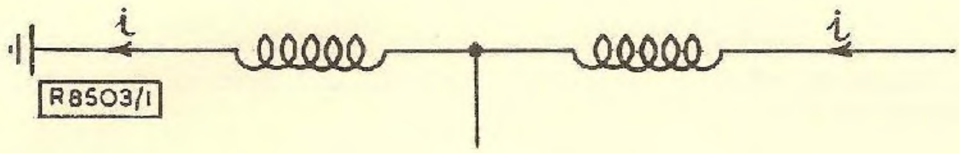

Fig. 8

If a current flows through the coils as in Fig. 8, then, the magnetic effects due to the two coils are additive, and the relay armature will move in one direction or the other, depending on the direction of the current.

Opposition differential duplex

Fig. 9 shows a simple form of opposition differential duplex circuit.

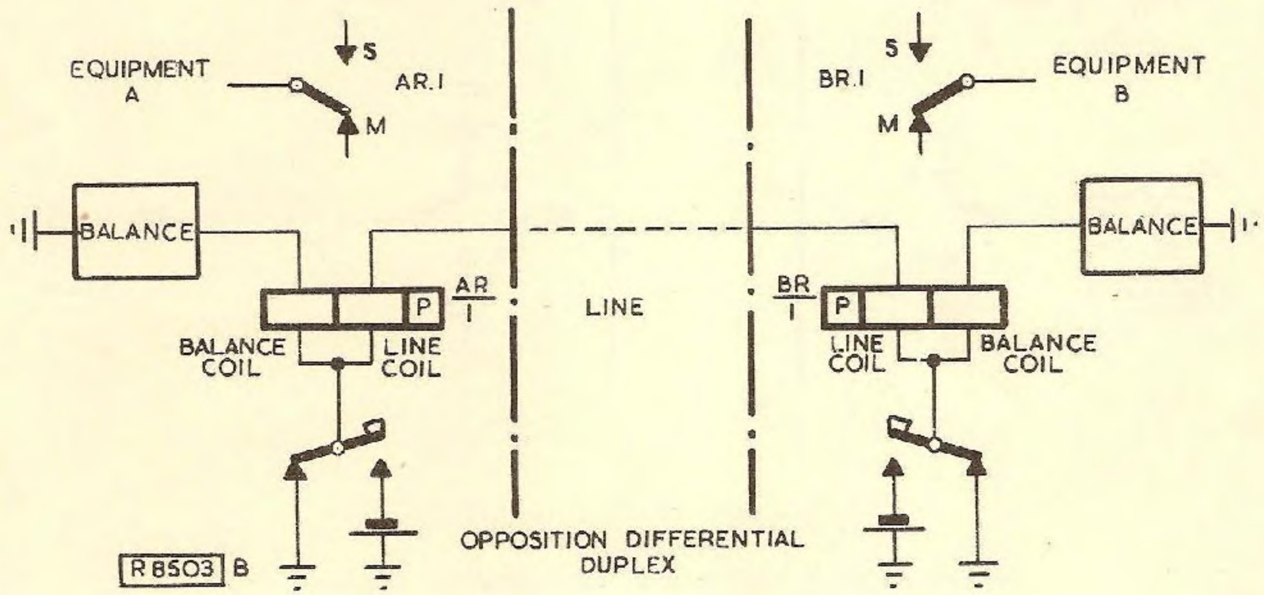

Fig. 9

The balance is an electrical network, built up from capacitors and resistors, which simulates the characteristics of the line, (including the receiving equipment) thus when the key at A connects the battery to line, the currents through the two relay coils at A give rise to equal and opposite magnetic effects, and the relay at A does not operate. The relay at B will operate, as current flows through the line coil but not in the balance coil.

When both keys are depressed, no current will flow in the line as the batteries are in opposition, but currents flowing in the balance circuits will cause the relays at A and B to operate.

When opposition differential duplex working is adopted using teleprinters and positive and negative supplies to provide spacing and marking currents, the circuit becomes as shown in Fig. 10.

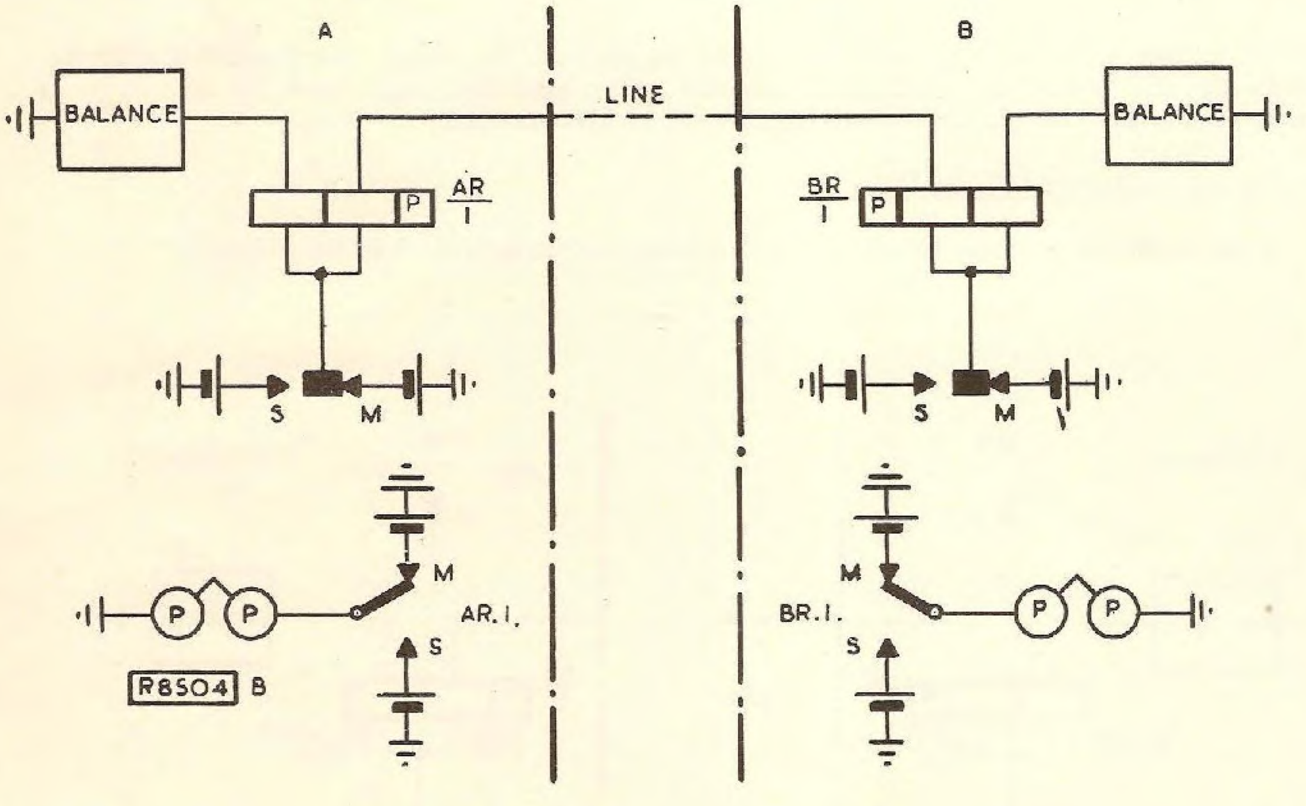

Fig. 10
Double current opposition differential duplex.

Consider the circuit condition shown in Fig. 10 where both transmitters are in the marking position. As the ends of the line at A and B are at the same potential, no current flows in the line or in the line coils of the relays. A marking current flows in both balancing circuits, so both relays are held in the marking position.

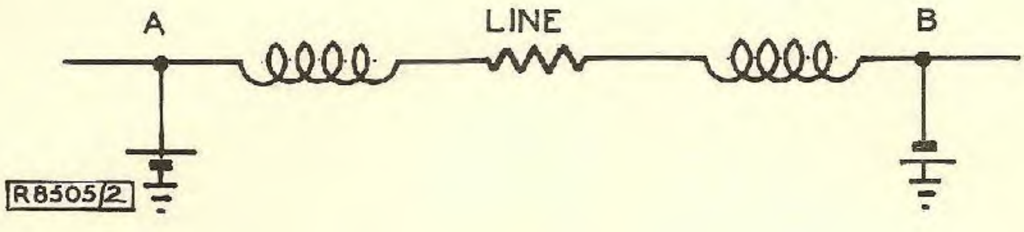

Fig. 11

When the transmitting tongue at A moves on to the spacing contact, the current in the balance circuit is reversed and the relay at A tends to space. Current is also passing through the line coils and as the two batteries have been placed in series in the line circuit, see Fig. 11, this current is approximately twice that flowing in the balance circuit, and is in a marking direction. The relay at A therefore remains in the marking position. The current in the balance circuit of the equipment at B tends to hold the relay at B in the marking position. The current in the line windings of the relay at B, however is in the spacing direction and, is twice the value of the current in the balance circuit. The relay at B therefore moves into the spacing position. A similar sequence is followed when the transmitter at B sends a spacing signal to A.

When both A and B extend a spacing signal to line, no line current flows and spacing currents in both balancing circuits hold both relays in the spacing position.

Position of transmitter at A	Position of relay at B	Position of transmitter at B	Position of relay at A
M	M	M	M
S	S	M	M
M	M	S	S
S	S	S	S

The above table summarizes the working of a double current opposition differential duplex circuit.

The balance network

The balance network, or artificial line, which is part of the balance or compensation circuit, is required to simulate the characteristics of the line. It is not sufficient for the steady current in the balance circuit to be equal to the steady current in the line. The instantaneous values of the two currents must be equal. If the line were very short it would be possible to use a resistor for this purpose, but in long circuits, particularly in the case of long underground circuits, the effects of the capacitance of the line must be considered. At the instant of reversal of a battery applied to such a line a current surge occurs owing to the line capacitance. In a duplex circuit this surge flows through the line coil of the relay and would cause the relay to "kick" if a similar surge were not allowed to pass through the balance network.

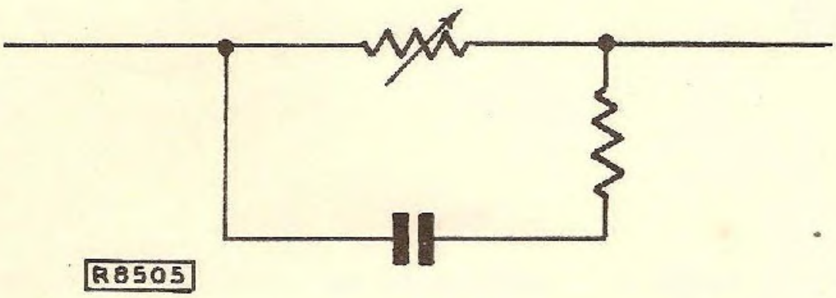

Fig. 12

A simple form of balance network is shown in Fig. 12.

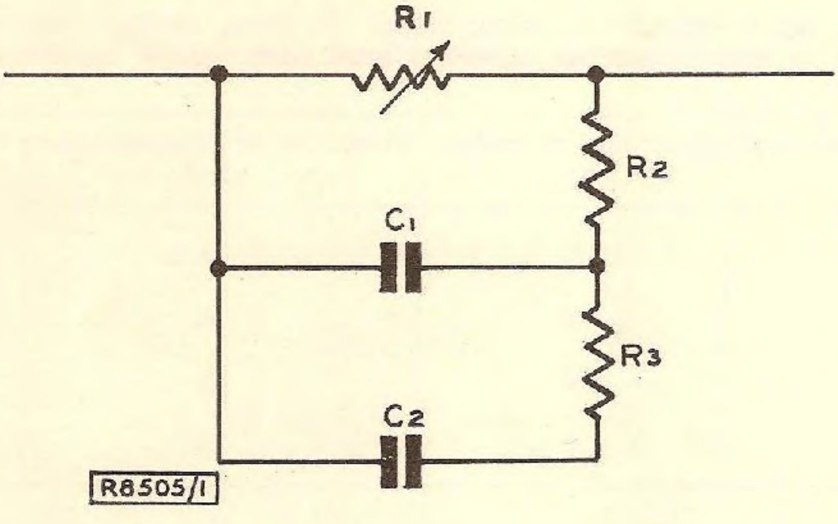

Fig. 13

For longer lines a more complex network is necessary a suitable one being shown in Fig. 13.

The longer the line, the longer the time taken for a current to reach its steady value, and therefore the longer must be the time taken to charge and discharge the capacitors in the compensation circuit.

A charged capacitor takes twice as long to discharge through a resistance of $2x$ ohms as it would through a resistance of x ohms. The energy stored in the capacitor is the same in both cases, but the rate of flow of the charge or discharge, varies. In Fig. 13, C1 discharges or charges via R2; C2 via R2 and R3. C2 can therefore be arranged to prolong the surge of current through the balance network.

Some of the components used in balance networks are made variable to enable an accurate balance to be made and to allow for small day to day variations in the line and equipment. The higher the speed of working of the system the more accurate the balance must be.

Bridge duplex

This system is based upon the principle of the Wheatstone Bridge and is not used for teleprinter working but is adopted in a modified form for long submarine cable circuits. (see E.P. Tg 2/2).

Duplex circuit using a four winding relay

Telegraph signalling on pairs in telephone cables has been developed in order to avoid the provision of special telegraph cables. In order that duplex working may be satisfactorily carried out, the telegraph circuit has to be arranged in such a manner as to cause no interference with telephone circuits. A relay, known as the "Relay 299 AN" is used for duplex working on telephone pairs. This relay has the following characteristics:-

(a) sensitivity, (b) accurately balanced windings, (c) stability of adjustment, (d) non-chattering contacts, (e) small transit time. The arrangement and numbering of the coils is shown in Fig. 14.

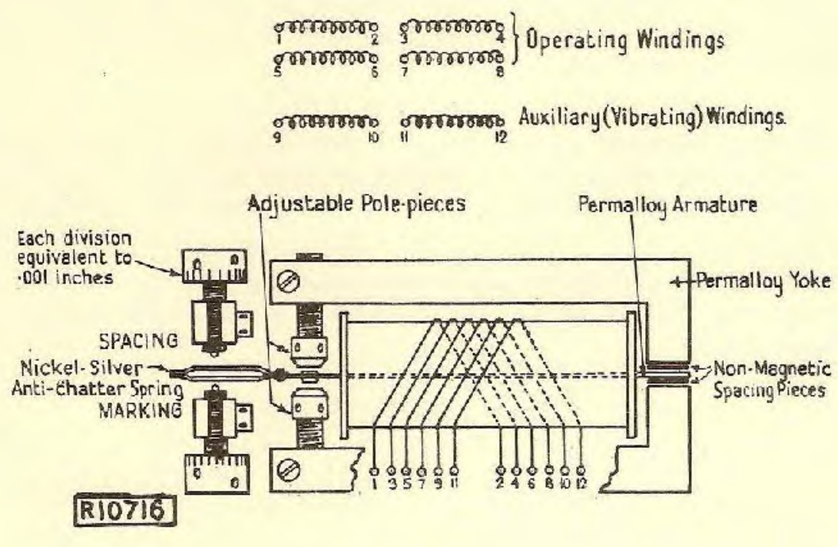

Fig. 14

A diagrammatic representation of the relay is shown in Fig. 15.

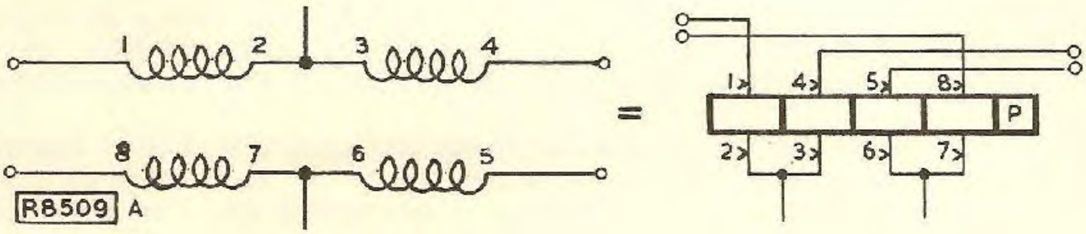

Fig. 15

Fig. 16 shows how the relay can be used for duplex working using teleprinters.

Interference from earth currents or from circuits in the same cable will cause currents to flow over both the A and B wires in the same direction. These currents flow through the relay coils in opposite directions and the effect on the relay armature is negligible.

For correct operation of the relays the current through the two windings associated with the balance must be equal (and opposite in direction) to the line current flowing in one winding of the relay associated with the A wire. The resistance of the balance network is therefore equal to the loop resistance of the line i.e. twice the resistance of the A wire.

The direction of winding of the coils is such that a current flowing from the odd to the even numbered tags causes the relay tongue to move to the spacing contact, and a current flowing from even to odd numbered tags cuases the relay tongue to move to the marking contact.

With both transmitting tongues at marking, a current flows from earth via the coils 7-8, balancing networks, coils 1-2 to negative battery via the teleprinter transmitter contacts producing a spacing effect on the armatures at X and Y.

A current also flows from the earth at Y via coil 6-5 at Y, A line, coil 4-3 at X to negative battery via the teleprinter transmitter contacts at X, producing a marking effect at both ends.

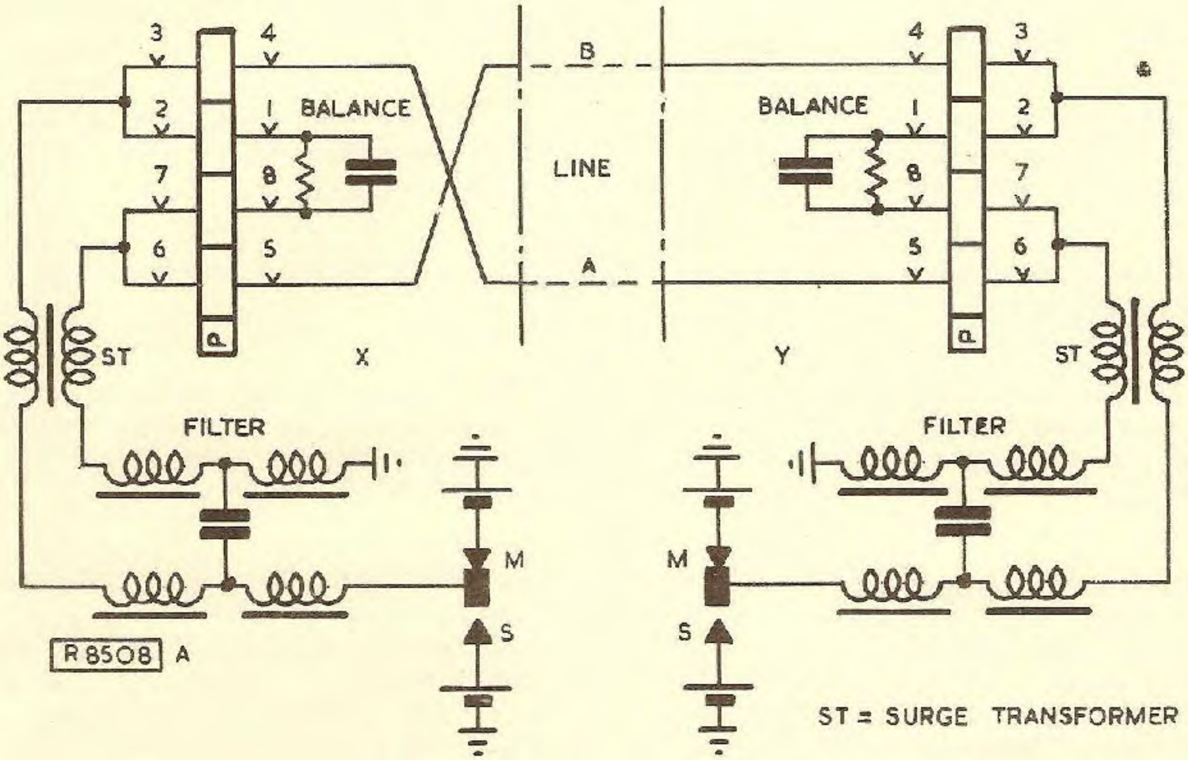

Fig. 16

Considering the condition of the circuit at X, and ignoring the coil 6-5 for the moment, then since the compensation circuit resistance is equal to twice the resistance of the A wire, the spacing effect of the compensation circuit is balanced by the marking effect of the coil 4-3 which may be explained as follows:- The resistance of the compensation circuit is twice that of the A wire and therefore the current in the compensation circuit is half that which flows in the A wire. However, since there are two coils in the compensation circuit and one in the line, the current which flows in the line coil produces the same magnetic effect upon the armature as half the same current flowing through the two coils of the compensation circuit.

A current also flows from earth at X via the coil 6-5 at X, B line, coil 4-3 at Y to negative battery via M contact and produces a marking effect at both ends. The arguments used for the end X also apply at end Y. In this condition therefore the relays at both ends of the circuit are held in the mark position because the marking current in the two line windings has twice the value of the spacing current in the two balance windings.

When the transmitting tongue at X moves to spacing, the direction of the current in the line coil 4-3 and compensation circuits is reversed, but owing to the balancing effect previously explained and the marking current still flowing in coil 6-5 at X, the relay at X remains at marking.

At station Y the effects of the line coil 4-3 and the compensation coils 7-8 and 1-2 are still equal and opposite and cancel each other but the current through the coil 5-6 is reversed and the armature moves to spacing.

Similarly when the transmitting tongue at Y moves to spacing, the relay at X moves to spacing.

When both transmitting tongues are on space the current in the relay balance windings produces a marking effect whilst the current in the line windings produces spacing. As already described for the marking condition the magnetic effect due to the line windings is predominant and thus both relays move to space.

In order that the surges of current which are produced by the rapid reversals of the battery shall not cause interference with other circuits in the cable, surge transformers are fitted, one winding being associated with the A and the other with the B wire. By the action of the transformer a surge of current into the A wire induces an equal and opposite surge into the B wire. The surge currents passing through the line and balance coils are equal and opposite and therefore the tongue of the relay remains on the marking contact under the control of the receive current.

The signals sent out by the transmitting contacts are sensibly square-topped. It can be shown that a square-topped wave consists of the fundamental frequency together with all the odd harmonics to infinity, in varying proportions. A reversal sent by a teleprinter consists of two signals each of 20 mS duration, so that a cycle lasts 40 mS.

25 such cycles occupy one second. Therefore the signal has a fundamental frequency of 25 c/s and odd harmonics of 75 c/s etc. The higher harmonics fall into the speech band and may interfere with adjacent audio-frequency telephone circuits. To minimize this interference, the transmitting circuit includes a low-pass filter, which cuts off the higher frequencies present in the telegraph circuit (those frequencies above 100 c/s) and consequently reduces interference between the circuits.

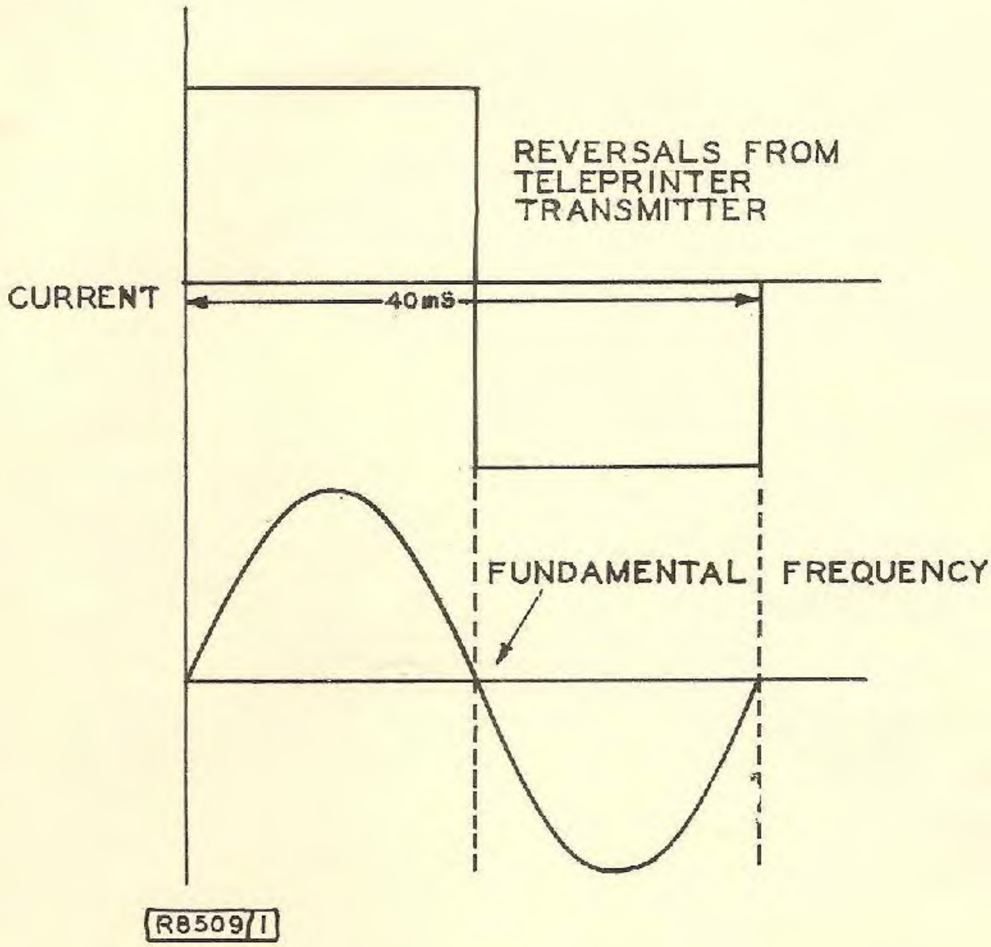

Fig. 17

This 4-winding relay circuit is operated from two twenty volt batteries and the current in the line circuit is limited to five milliamperes, to reduce the amplitude of the harmonics produced. The relay used in this circuit is provided with a vibrating circuit to increase its sensitivity.

SUB-AUDIO WORKING

Principles

In telephony, the range of frequencies required is 300 to 3400 c/s. Since the frequencies in telegraphy are usually low, it is possible to work a telegraph and a telephone over the same line simultaneously if filters are provided to prevent the one interfering with the other. Such circuits are known as "Composited" circuits. Another name given to this arrangement is "Sub-audio" telegraphy. A schematic diagram of a composited circuit is shown in Fig. 18.

The high-pass filters prevent the telegraph signals from interfering with the telephone circuit, and the speech currents are not of sufficient magnitude to interfere with the telegraph circuit.

A low-pass filter must be included at the sending end to prevent the harmonics of the telegraph signals from entering the line, since these are of high frequency and extend into the telephone range. They would therefore pass through the high-pass filters and cause interference to the telephone circuit.

A low-pass filter is necessary at the receiving end because the movement of the receive-relay armature generates frequencies which are in the telephone range. These are prevented by the filter from passing back to line.

The high-pass filters have a cut-off frequency of about 200 c/s and pass all frequencies above this. The low-pass filters usually cut off at about 60 c/s.

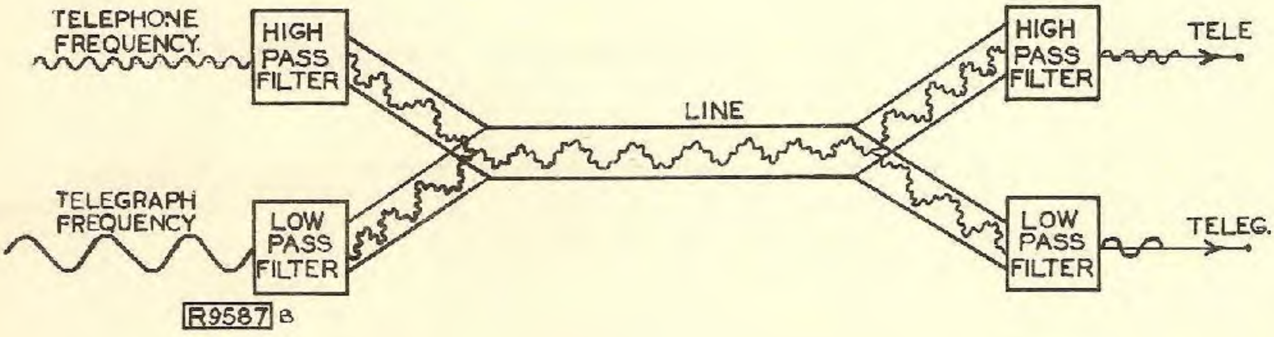

Fig. 18

Ordinary telephone ringing-current used on generator-signalling trunk circuits has a frequency of 17 c/s. Since this comes in the telegraph range it is necessary to adopt some other frequency for the signalling current. A frequency of 500 c/s interrupted 20 times per second is used.

The efficiency of telephone repeaters falls off very rapidly at frequencies below about 200 c/s so that in effect low frequencies will not be transmitted by them. To overcome this difficulty the repeaters have to be by-passed. This is done by routing the telegraph signals round the repeater via low-pass filters. This is shown in Fig. 20 which shows a complete 2-loop simplex sub-audio circuit.

The smoothers and low-pass filters are separate units, (Fig. 19) but the smoother is so designed that together with the low-pass filter unit it forms a two section low-pass filter. This is necessary only at the sending end, the low-pass filter alone being sufficient to by-pass repeaters at the receiving end.

Signals from the teleprinter pass into the "A" line of the loop via the regulating resistance, one winding of the surge (or kick) transformer, one coil of the differential milliammeter, one side of the smoother and low-pass filter.

The high-pass filter blocks these low-frequency signals from entering the local side of the telephone circuit. At the repeater station the telegraph signals by-pass the repeater via one half of the low-pass filters on each side of the repeater, the high-pass filters preventing them from entering the repeater.

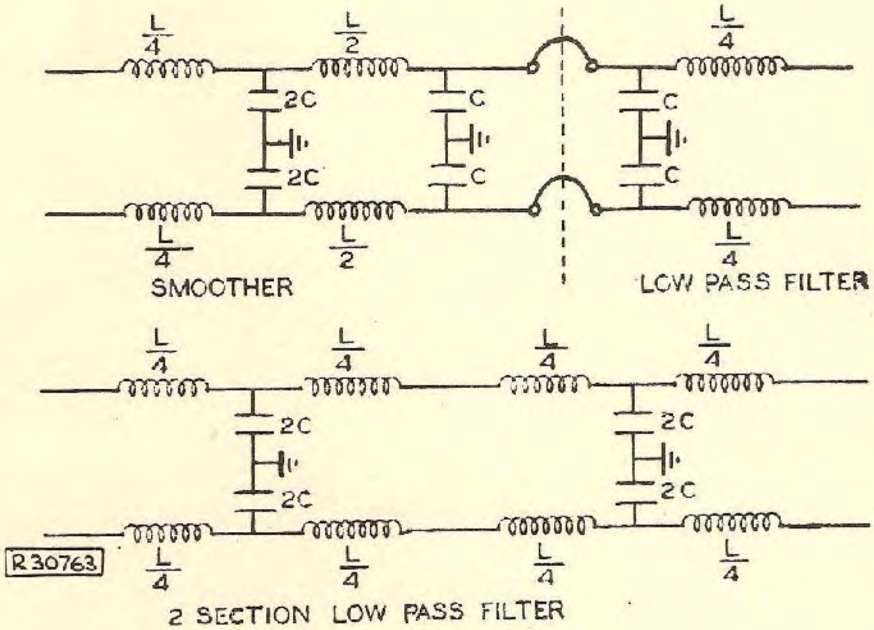

Fig. 19

At the receiving end the signals pass through the receiving relay and back to the "B" line via the low-pass filter. Here again the high-pass filter prevents them from entering the local telephone circuit. The path of the signals back via the "B" line may be readily traced in Fig. 20.

The receiving relay is of the vibrating type and is set to 25 c/s, corresponding to 50 bauds, the normal speed of a teleprinter. The vibrating relay is necessary because of the low line-current available on long circuits.

Speech currents pass to line via the high-pass filter and after amplification at the telephone repeater are received at the far end through the receiving high-pass filter.

In all cases the voice-frequency currents are blocked from the telegraph circuit by means of the low-pass filters. The 0.5 μF capacitor connected in the middle of the telephone side of the transformer winding serves as an additional protection against any low-frequency disturbance entering the telephone circuit. It does not degrade the telephone speech to any appreciable extent.

In this particular case speech transmission takes place in both directions, since 2-wire telephone circuits are used. In the case of the telegraph, however, a second telephone loop is used for transmission in the opposite direction. The circuits are identical as may be seen from Fig. 20.

This system is capable of a speed of 80 bauds with a line current of 3 mA on a 250 mile circuit.

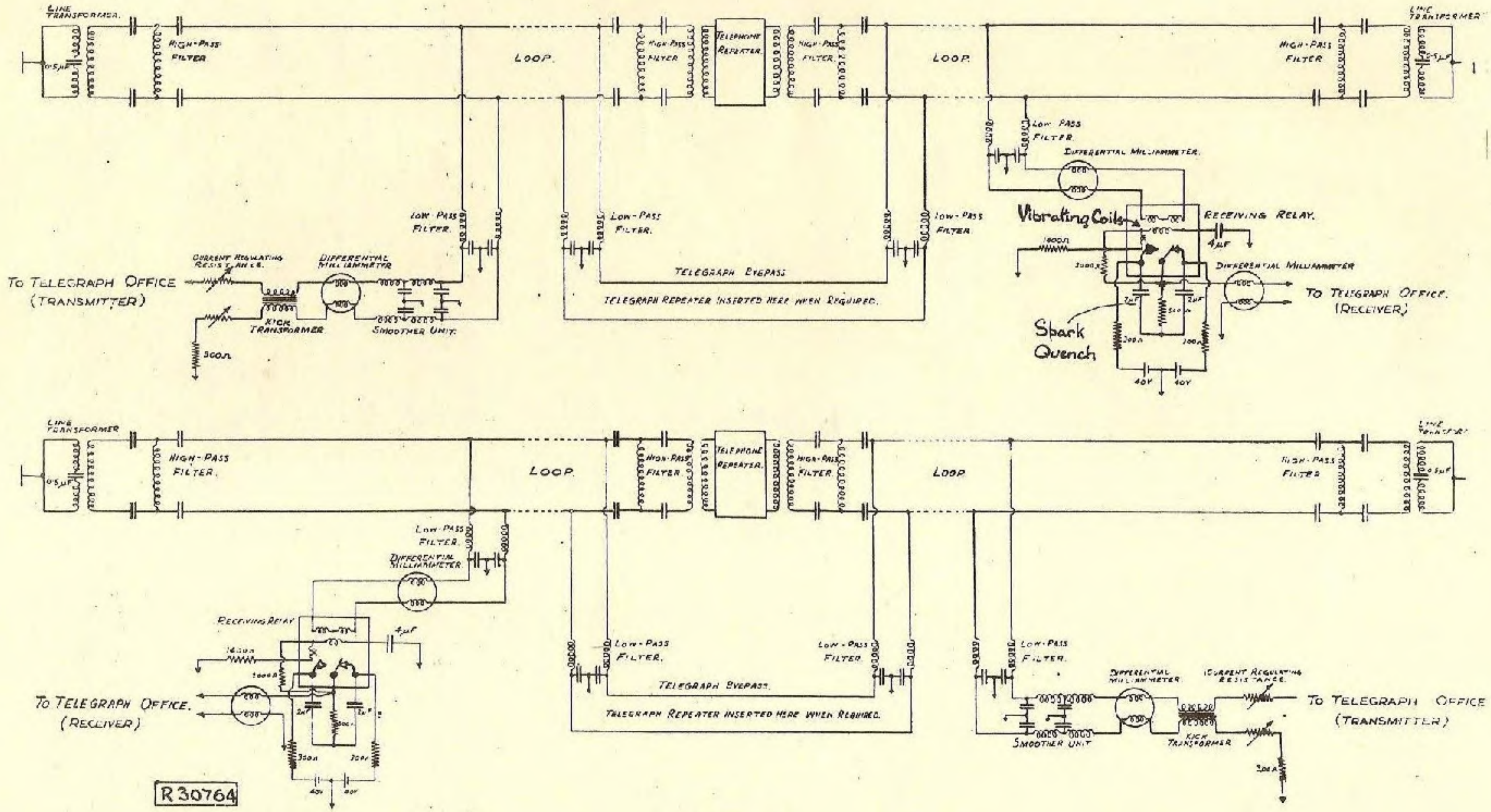
LINE TRANSFORMER
HIGH-PASS FILTER
LOOP
TELEPHONE REPEATER
LOW-PASS FILTER
DIFFERENTIAL MILLIAMMETER
Vibrating Coils
RECEIVING RELAY
TO TELEGRAPH OFFICE (RECEIVER)
Spark Quench
CURRENT REGULATING RESISTANCE
TO TELEGRAPH OFFICE (TRANSMITTER)
KICK TRANSFORMER
SMOOTHER UNIT
TELEGRAPH BYEPASS
TELEGRAPH REPEATER INSERTED HERE WHEN REQUIRED.
R 30764

Fig. 20

SUPER-AUDIO WORKING

In voice-frequency telegraphy it is possible to convey telegraph signals by means of alternating currents. The carrier frequencies used are chosen to lie in the voice range because telephone lines are designed to transmit this range, but the same principle could be used, whatever the frequencies, provided that the telephone line will transmit those frequencies. If the frequencies chosen are above the range necessary for commercial speech then the system is known as a super-audio or supra-acoustic telegraph.

The attenuation and distortion of an underground line may be reduced by connecting inductance coils at regular intervals in series with the line. An attendant effect is that the line is then equivalent to a low-pass filter and beyond a certain frequency, known as the cut-off frequency, the attenuation increases very rapidly. (See Fig. 21). The highest frequency that can be transmitted without undue attenuation depends on the amount of added inductance.

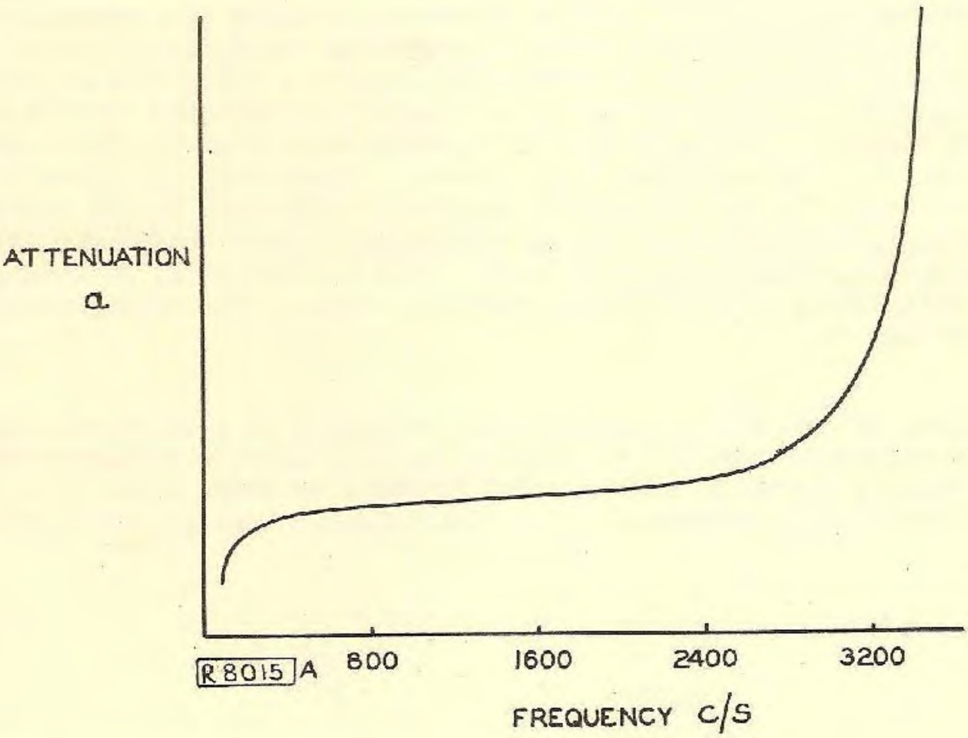

Fig. 21

In the present telephone-cable network various degrees of loading exist and the cut-off frequency varies from 2600 c/s - a commercial minimum - to about 7000 c/s. The object of super-audio working is to make use of the band above the range necessary for commercial speech by providing telegraph channels whose carrier frequencies are in this band. The audio frequencies may already be used for an 18-channel voice-frequency telegraph system, in which case additional channels may be obtained on the same 4-wire circuit by employing frequencies above the voice range.

With a cut-off frequency of 7000 c/s it may be possible to provide, say, two telephone channels, one by carrier methods. Briefly, the principle behind carrier telephone systems is to transfer the speech frequencies en bloc to a higher band by modulating a carrier frequency with the speech frequencies. For instance, if a frequency range of 300 to 2600 c/s modulates a carrier frequency of 6000 c/s, upper and lower side-bands of 6000 + 300 c/s to 6000 + 2600 c/s and 6000 - 300 c/s to 6000 - 2600 c/s will be produced. Thus the upper side-band is from 6300 to 8600 c/s and the lower from 5700 to 3400 c/s. Now either of these side-band ranges contains the speech intelligence and may be selected by means of a band-pass filter; the lower side-band is usually used. When mingled in the line with audio-frequencies, the audio and the carrier telephone frequencies may be separated at the receiving end by means of band-pass filters just as the channels in a multi-channel voice-frequency telegraph system are separated. By a process known as demodulation, the original speech frequencies are obtained from the side-band frequencies.

Whenever the cut-off frequency of the cable appreciably exceeds the band required for commercial speech, and carrier telephone circuits if provided, the spare frequency range is a potential means of providing telegraph circuits. For instance, in the case of one 4-wire underground circuit, a 2-way simplex telegraph circuit operating with a carrier frequency of 2940 c/s is provided as well as the normal telephone channel. The principle of working is similar to that employed on any one channel in a multi-channel V.F. system. Where only one circuit is provided by these means the arrangement is similar in principle to the sub-audio case but the telegraph signals pass through high-pass filters whilst the telephone speech currents pass through low-pass filters. The filters will, of course, prevent telegraph from interfering with telephone and vice versa. The arrangement is shown schematically in Fig. 22.

A disadvantage of working a single carrier telegraph on a telephone circuit is the complication of maintenance due to sharing the line between telegraph and telephone, but where a number of channels are possible or where there is a shortage of telegraph circuits on a particular route, this disadvantage is outweighed.

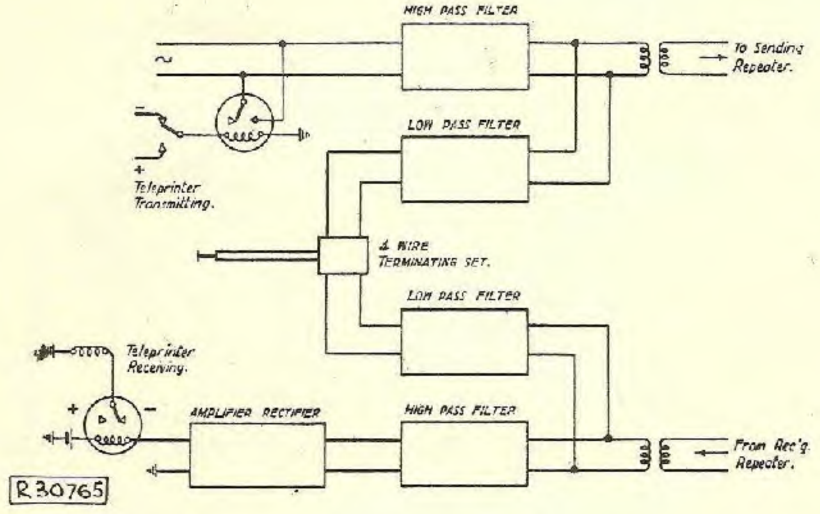

Fig. 22

Since a carrier telephone channel transmits a range of frequencies suitable for commercial speech, it can be used for an 18-channel voice-frequency system. The output from a normal system is used to modulate a suitable carrier frequency in order to transfer the normal audio range to the required band in the super-audio range. At the receiving end the carrier channel is selected by means of a high pass filter and after transferring back to the audio range by demodulation, the output is suitable for extension to the receiving filters of the normal 18-channel equipment. Where good underground cables are available the use of an audio channel is preferable on the grounds of simplicity but it has been found, in countries where carrier working on long open wires is used appreciably, that carrier channels may be preferable as being subject to less electrical interference.

A number of underground cables exist in this country, the loading of which is such that the cut-off frequency is not sufficiently high to permit the working of a carrier telephone circuit. In these cases it is possible, however, to obtain seven or eight super-audio telegraph channels by using normal carrier-telephone apparatus with a carrier frequency of 6000 c/s., say, but modulated by only the upper frequencies of the standard 18-channel system. In this case, for eight channels the lower side-bands (i.e. carrier minus modulating frequencies) resulting from modulating a 6000 c/s carrier with the eight frequencies 1620, 1740, 1860, 1980, 2100, 2220 and 2340 c/s would be 4380, 4260, 4140, 4020, 3900, 3780, 3660 and 3540 c/s. These frequencies would therefore be transmitted over the line in addition to the band 300-2600 c/s required for the audio telephone circuit.

The line and filter attenuation characteristics are shown in Fig. 23.

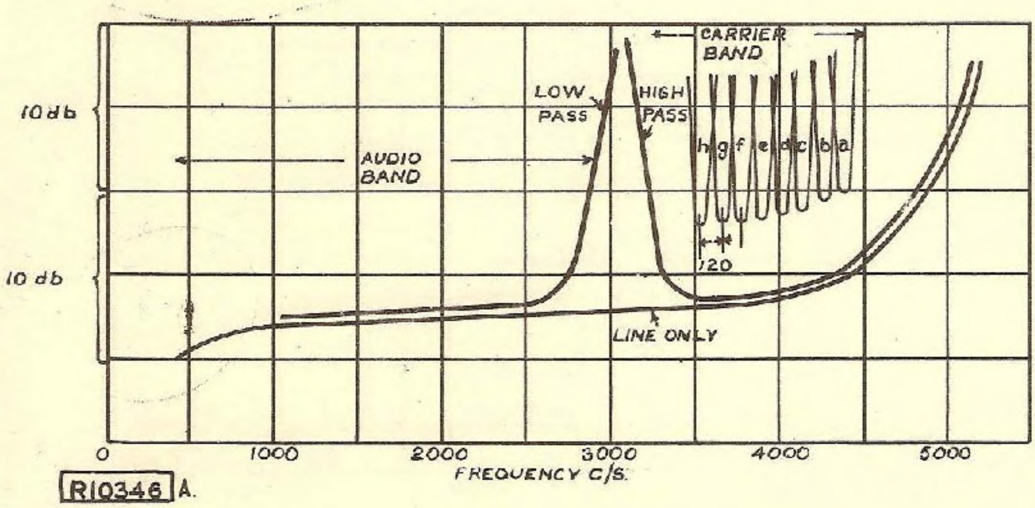

Fig. 23

END