No. 178

The Institution of Post Office Electrical Engineers.

Long Distance D.C. Impulsing

S. WELCH, M.Sc. (Eng.)

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A Paper read before the Harrogate Sub-Centre on the 13th February, 1942, and at other Centres during the Session.

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1. INTRODUCTION.

In recent years the policy of automatisation has introduced many impulsing problems, and considerable development has been undertaken in an effort to extend the dialling range. Increased dialling range has lately become more necessary to meet the following aims:—

(*a*) To enable subscribers to complete calls automatically within 15 radial miles from the originating exchange.

(*b*) To enable Trunk and Toll calls to be completed with the assistance of one operator only.

The usual D.C. impulsing methods are:—

(*a*) Loop Dialling, and

(*b*) Battery Dialling,

and these methods are subject to considerable limitation regarding the permissible limits.

Recent achievements which increase the dialling range are:—

(*c*) Long Distance D.C. Impulsing.

(*d*) 2 V.F. Impulsing.

The L.D.D.C. system, about to be described, was developed as a comparatively inexpensive method of extending the dialling range on audio circuits.

Transmitting dialling signals by A.C. is the Department's standard method for the longer lines, and 2 V.F. working is now in operation between Zone Centres.

2. REVIEW OF IMPULSING SYSTEMS.

Loop Dialling.

The maximum single junction resistance for non-reactive lines, 50-volt working, is 1500 ohms. In tandem connections the maximum number of junctions should not exceed three, the overall resistance not exceeding 1500 ohms, consequently the maximum resistance of any one tandem link is considerably below 1500 ohms and is usually of the order of 800 ohms. These limits are, of course, qualified by the particular type of equipment used.

Battery Dialling.

This method is used extensively for dialling from Manual Boards into distant automatic equipment. Since impulsing takes place over one leg it is possible to dial over circuits of higher resistance than Loop Dialling will permit, the limit being 2500 ohms for 50-volt working over non-reactive lines. Due to the leg impulsing condition the junction is unbalanced and gives rise to disturbances on other circuits, this, however, is not serious on unamplified lines.

Regenerators.

It is possible for each junction in a tandem train to have limits comparable to the single junction case by the use of the Mechanical Impulse Regenerator. Theoretically, an unlimited number of junctions can be worked in tandem by the use of Regenerators, but considerations other than purely impulsing, preclude such an arrangement. Thus the advantage of the Regenerator lies mainly with increasing the limits of the individual links of a tandem train, the maximum single link usually not being increased above 1500 ohms.

Amplified Lines.

The modern tendency is to use small gauge conductors and amplifiers, and a great deal of 4-wire Star Quad amplified cable circuits will be met with in future. D.C. dialling can be applied to these circuits over a metallic circuit which is arranged for.

The Loop Dialling limit over these reactive lines is 1500 ohms, being much the same as that over non-reactive lines.

In the case of Battery Dialling, however, the single junction limit is considerably reduced. The phantoms of 4-wire Star Quad circuits are not balanced against cross-talk, and the disturbance aspect reaches such large proportions that generally it is not desirable to use Battery Dialling over amplified lines. In addition the terminal and line capacity effects reduce the permissible line limit, for example the 50-volt limit is reduced from 2500 ohms to 600 ohms, a considerable decrease.

L.D.D.C. Impulsing.

Thus, apart from any possible schemes of impulse correction which may be developed in the future, the maximum single link resistance with existing D.C. Loop Impulsing over reactive lines is 1500 ohms. Consequently, development was centred on increasing this limit and the Long Distance D.C. Impulsing System was produced.

The limit for this system is 100 miles of 20 lb. 4-wire Star Quad amplified cable, representing 4,800 ohms resistance, but it will be seen later that the limit is actually based on the CRl^2 value of the line where l represents the length in miles. The system can only be applied to circuits where a metallic connection exists throughout the signalling loop, but such a loop is provided, or can be made available, on 4-wire circuits.

The classes of circuits over which impulsing must be achieved fall into the following categories:—

(1) Carrier frequency circuits.

(2) Repeatered high quality physical circuits in which by-product channels are valuable.

(3) Amplified circuits on which a metallic loop can be made available.

(4) Unamplified local cable circuits.

Categories (1) and (2) invariably necessitate the use of A.C. signalling systems owing to the impracticability of providing a separate metallic signalling circuit for each channel. The 2 V.F. Signalling System adopted by the Department for providing impulsing facilities over these classes of circuits has already been adequately described elsewhere.[1]

Circuits in category (3) up to a length of 100 miles of 20 lb. 4-wire Star Quad amplified cable can be dealt with by the L.D.D.C. Impulsing System. Un-

[1] I.P.O.E.E. Paper No. 162.

amplified local circuits can be operated on a loop dialling basis with the use of Mechanical Impulse Regenerators when required.

3. EARLY EXPERIMENTS ON L.D.D.C. IMPULSING.

The length and number of junctions over which dialled impulses may be sent is limited by the insensitivity and distortion of the 3000-type impulsing relay. An ideal impulsing relay is one which operates in series with high resistance and has a minimum difference between operate and release times at all values of series resistance from zero to maximum.

A sensitive relay, S.T. & C. Code 4123F, by virtue of its construction has small operate and release times, with only slight variations over a wide range of series resistance, and it was thought to be particularly suitable for impulsing over long lines.

Preliminary tests, from a direct impulsing aspect only, indicated that the relay, even when modified to incorporate nickel-iron sleeves for high impedance, impulsed with a series N.I. resistance of 8000 ohms. This result was thought to be sufficiently encouraging to examine such a scheme in further detail.

In order to examine the performance of the sensitive relay when connected in a transmission bridge, a preliminary circuit was designed employing the basic principles of Fig. 1, in which AP is the sensitive relay. It was quickly found that the scheme introduced two distinct problems:—

(1) Distortion of signals due to the heavy surges which occur when current in the selector "A" relay is broken by contact AA1.
(2) The distortion of signals due to the reactive elements of the line.

With regard to (1), the sensitive relay is particularly responsive to surges, and the conclusion was reached that the most suitable method of overcoming the difficulty would be to obtain a pre-dialling signal, this signal being used to divorce the receiving relay from all incidental apparatus during dialling, normal speaking conditions being reconnected to the line at the end of the dialling period.

With regard to (2), the reactive properties of the line caused the current arrival and decay curves to be gradual, the decay curve particularly so, and as the line length increased, interference between successive signals rendered the arrangement unworkable.

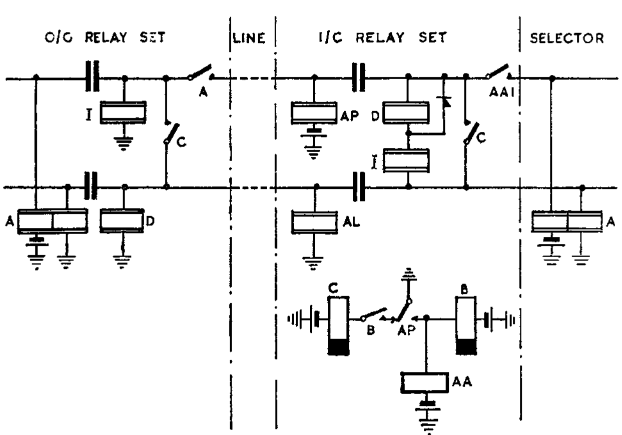


FIG. 1.—SENSITIVE IMPULSING RELAY APPLIED TO LOOP DIALLING CIRCUITS.

The arrangement shown in Fig. 1 was therefore abandoned, and consideration was given to methods of:—

(*a*) Improving the build-up time of the current arrival curve, and sharpening the decay.
(*b*) Isolating the impulse receiving element from the transmission bridge during dialling periods.

Two methods of accomplishing (*a*) were presented, one by transmitting double current signals and the other by transmitting single current signals and terminating the line on the primary of a transformer, the arrival and decay curves being differentiated to obtain double current effect. This latter method was finally adopted. The method by whch (*b*) was accomplished is described in Section 7 of the paper.

4. IMPULSING ELEMENT.

Sending Circuit.

There are a number of single current methods of transmitting D.C. signals, the usual method being loop dialling, Fig. 2. Signals are generated by contact A making and breaking, and the arrival and decay curves are of different shape, the decay being more gradual than the arrival on reactive lines.

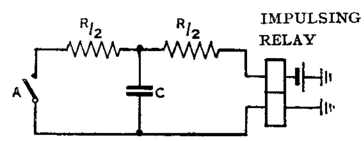


FIG. 2.—LOOP DIALLING—SKELETON CIRCUIT.

This arrangement is quite satisfactory over lines which have small capacities, but where capacity effects are large, the line becomes discharged during the time the impulsing contact is closed, and when the contact is opened the line capacity charges through the coils of the receiving end relay, with the result that the relay is very slow to release. In fact, on lines where the capacity is very large, the relay may not release during the break period.

As a condition for correct signalling is that the decay curve must reach complete zero before the next arrival curve begins, the next pulse would have to be delayed and thus impulsing would have to be slowed up. Should the next pulse arrive while the decay current is flowing, the second arrival curve would be different from the first, the actual current being the algebraic sum of the two considered separately. It is obvious that advantage would be gained if the decay curve were made more steep.

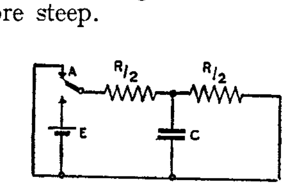


FIG. 3.—SYMMETRICAL IMPULSING—BASIC CIRCUIT.

Consider the arrangement as shown in Fig. 3. In this case signals are generated by changing the sending battery from 0 to E volts. The arrival curve is much the same shape as that with loop dialling. At the end of the contact made period the line is short-circuited at the sending end. This may be regarded as equivalent to the insertion of an equal and opposite E to neutralise the first E, the algebraic sum E + − E being zero. This −E gives rise to an arrival curve, the same shape as that originally produced by +E,

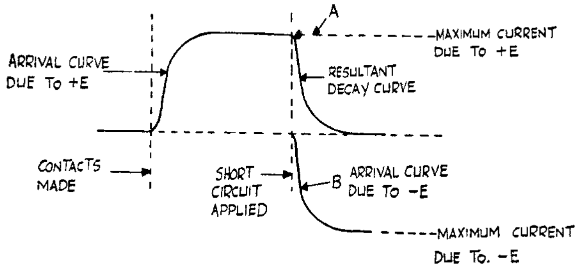


FIG. 4.—SYMMETRICAL ARRIVAL AND DECAY CURVES

but in the reverse direction as shown in Fig. 4. The resultant decay curve is obtained by the algebraic sum of current A produced by +E assumed to be still applied at time of short circuit, and the arrival curve B due to −E. Consequently the decay curve is steeper than that of loop dialling, and the condition that the received current should reach its steady state during each interval is improved. In addition the arrival and decay curves are symmetrical in shape, which, as will be seen later, is a fundamental condition of the L.D.D.C. Impulsing System. It will also be appreciated that this arrangement permits a higher speed of signalling than loop dialling. As will be seen later a mechanical impulse regenerator is employed to generate the impulses at the sending end. This has a simple make contact, and Fig. 3 using a change-over contact can be adapted as Fig. 5. Suitable values of

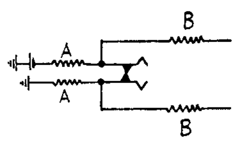


FIG. 5.—SYMMETRICAL IMPULSING—TRANSMITTING ARRANGEMENT UTILISING MAKE CONTACT.

resistors A and B will enable this arrangement to generate signals similar to those of Fig. 3, and in addition the arrangement provides a generator which is well balanced to earth.

While Fig. 3 gives symmetrical arrival and decay curves, the build-up time of the arrival curve is relatively long. The square-topped transmitted voltage signal can be represented by a Fourier Series of sufficiently low fundamental frequency as shown in Fig. 6, and the reason for the long build-up time is

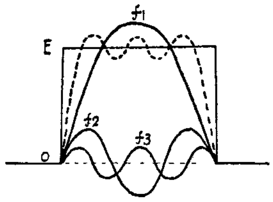


FIG. 6.—FOURIER ANALYSIS OF SQUARE TOPPED SIGNAL.

to be found in the reactive properties of the line causing a rapid increase in attenuation with frequency so that amplitudes of the higher frequencies are considerably reduced compared with the fundamental, and on long lines the tendency is for the fundamental only to survive at the receiving end. Phase distortion is also a factor, but this effect is minimised by the limited range of frequencies passed by the filters.

Receiving Circuit.

Assuming the sending circuit as described above and a suitable relay at the receiving end, it is clear that the relay would only produce distortionless signals if it were specially adjusted with respect to operate and release currents, thus necessitating a separate relay adjustment for each length of line (an undesirable feature), together with equal operate and release times.

The fundamental requirements of a receiving relay terminated arrangement are:—

(1) Sufficient received power to operate the relay.
(2) Steep fronted signals to mark the beginning and end of each impulse.

The necessity for the first requirement is obvious, but mention of it cannot be ignored since it is quite possible to produce impulses of good wave shape without the necessary power for operating the relay. The second requirement determines the stability of the impulse repetition, the steeper the front of the signal up to the operating point of the relay, the less the impulse will be affected by changes of line length and mechanical changes in the relay. The inductance of the receiving relay and the inclusion of filters at the sending and receiving ends still further increase the build-up time of the arrival curve. Consideration was given therefore to methods of improving the wave shape and subsequently applying this improved signal shape to the receiving relay.

Improvement of Signal Shape.

It has previously been mentioned that the build-up time of the arrival curve is long, due to the fact that the attenuation of the line is rapidly increased with frequency. If this same line is terminated on an inductance of L henries, the reactance of which will increase with frequency, then from a voltage point of view this increase in terminal impedance will in some measure compensate for the increase in attenuation of the line with frequency.

The resistance r ohms of the receiving inductance is important, as the time constant L/r has a considerable effect on the received signal shape. There is a relation between the time constant of the inductance and that of the line for best wave shape, and this implies a separate adjustment of L/r for each line length, but it has been found possible to obtain a marked degree of signal shaping by making one adjustment to the time constant of the inductance throughout the range of line lengths. As will be seen later the time constant of the inductance is varied by means of a N.I. shunt.

Thus line equalisation over the essential frequency range is obtained on a voltage basis by terminating the line on an inductance. In order to use the voltage across the inductance, the line has been terminated on a transformer, the L/r being satisfied by the primary winding. The received voltage waves across the secondary consist of steep fronted double voltage signals as shown in Fig. 8.

Unfortunately, the received power at the secondary is insufficient for direct relay operation. In addition, the resulting transformer secondary load would change the impedance looking into the primary, such that the signal shape would be spoiled. Accordingly a valve was interposed between the input transformer and receiving relay, the steep wave fronts on the secondary accurately marking the beginning and end of the signals.

Complete Impulsing Circuit.

This is shown in Fig. 7. The receiving relay PR being a double winding polarised type.

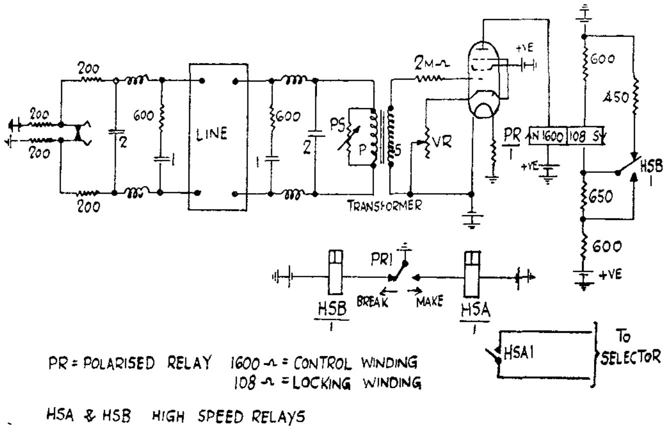


Fig. 7.—L.D.C.C. Impulsing Circuit Elements.

Polarised Relay.

Relay PR is included in the valve anode circuit. A nominal anode current of 10 mA from the valve flows in the control (1600 ohm) winding of PR, and the PR1 contact is required to move to the " Make " position in response to an increase in anode current and to the " Break " position in response to a decrease. These requirements are achieved by using a magnetically polarised relay of the balanced armature type, having two windings differentially connected. The direction in which the anode current flows through the control winding is such that it tends to move the armature to the " Make " position, while current in the locking (108 ohm) winding tends to move the armature to the " Break " position. If the magnetic force produced by the locking winding exactly neutralises that produced by the nominal anode current of 10 mA, then the armature will take up a neutral position and an increase in anode current will produce a stronger force in the " Make " direction, whilst a decrease in anode current will allow the force produced by the locking winding to predominate and move the armature to the " Break " position. With a simple arrangement such as this, however, the armature would return to its neutral position before the termination of each impulse period, *i.e.*, as soon as the signal voltage on the grid of the valve had disappeared and allowed the anode current to resume its nominal value. Hence arrangements are made to lock the armature in the position to which it has been moved until the termination of the relevant impulse indicated by change of anode current in the opposite direction. Thus the magnetic force produced by the locking winding does not exactly neutralise the magnetic effect of the control winding. It is arranged that movement of the PR1 contact to " Make " reduces the current in the locking winding such that it produces a magnetic force only 50% as strong as that produced by the nominal anode current in the control winding. While the PR1 contact is in the " Make " position, therefore, the control winding exerts a superior magnetic influence, thus providing the requisite contact pressure. A reduction in anode current to 50% of its nominal value will restore the condition of balance and allow the armature to assume a neutral position once more, while a reduction below 50% will permit the locking winding to exert a superior magnetic influence and move the armature to the " Break " position.

The receipt of the break impulse therefore unlocks the PR1 contact from the " Make " position by arranging for the closure of the break contact to treble the current flowing in the locking winding. In this way the magnetic force produced by the locking winding rises to 150% of that produced by the nominal anode current in the control winding, thereby maintaining the armature and providing adequate contact pressure after the anode current has been restored to its nominal value.

It follows, therefore, that on arrival of the subsequent make impulse the anode current must rise to more than 150% of its nominal value to overcome the magnetic force produced by the locking winding before the PR1 contact can be unlocked and moved to the " Make " position.

Thus during impulsing a decrease in anode current at the commencement of a break impulse moves the armature to the " Break " position where it remains until, at the termination of this impulse, the rise in anode current moves the armature to the " Make " position. Owing to the completely balanced design of the relay, and the identical nature of both make and break signals, the PR1 contact responds with equal operate lags on movement from Make " and movement from " Break," thereby minimising impulse distortion.

Referring to Fig. 7, on seizure PR1 is in the " Make " position, HSA is operated, and the selector seized. When the impulsing contacts open to send a break pulse, the rise of current in the primary induces a negative signal voltage on the secondary, which, applied to the grid of the valve, causes the anode current to fall almost to zero. When the anode current falls below 5 mA, PR1 contact moves to " Break " under control of the locking winding, relay HSB operates and HSA releases.

HSA1 opens the loop to the selector to transmit the break pulse.

HSB1 removes the 450 ohm shunt from the locking winding, and short-circuits the 650 ohm resistor. The value of current in the locking winding is thereby trebled and PR locks in the " Break " position.

When the current change in the primary ceases and current reaches a steady state, the induced voltage in the secondary falls to zero, and the anode current returns to its nominal value 10 mA, but the locking winding force exceeds that of the control winding and PR1 is held in the " Break " position.

At the end of the break impulse, the impulsing contacts close, causing the current in the primary to fall to zero, and during the current decay, the positive signal voltage which is induced on the secondary is applied to the grid of the valve. The anode current therefore rises, and when it exceeds 15 mA, the control winding force overcomes that of the locking winding and PR1 contact moves to the " Make " position. Relay HSA operates and HSB releases.

HSA1 closes the loop to the selector to transmit the make pulse.

HSB1 removes the short circuit from the 650 ohm resistor and replaces the 450 ohm shunt, thereby reducing the locking winding current to one-third of its former value and PR1 contact is locked in the " Make " position.

When the current change in the primary ceases, the induced voltage on the secondary falls to zero, the anode current returns to its nominal value of 10 mA, but contact PR1 remains locked in the " Make " position under the superior influence of the control winding.

Fig. 8 shows the conditions in the primary, secondary and anode circuits during impulsing.

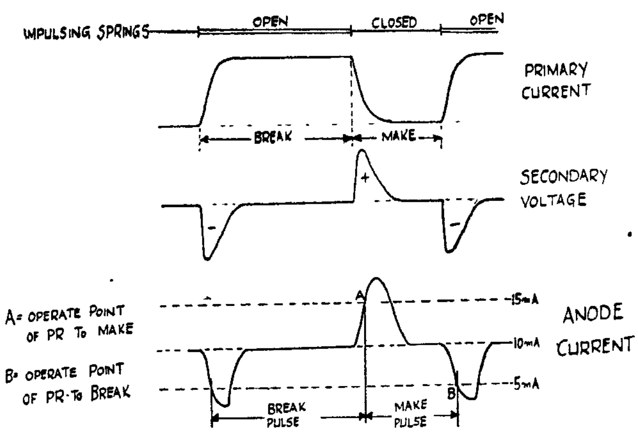


FIG 8.—CURRENT AND VOLTAGE EFFECTS DURING IMPULSING.

Details of Valve Circuit.

The valves used are V.T. 103B. The 2 megohm grid resistor, in addition to providing a no load condition for the input transformer, also limits the anode current so that the polarised relay is working approximately between fixed current limits irrespective of line length. The upper value of the anode current being limited to between 20 and 30 mA depending on the age of the valve. The bias resistor VR serves to adjust the nominal anode current, and furthermore ensures that the value of the anode current is relatively independent of battery voltage variations. In addition, VR reduces the mutual conductance of the valve circuit to about 20% of its nominal value so that the arrangement will be less subject to changes resulting from variations in valve characteristics.

The valve is biassed to approximately the mid point of its " anode current grid volts " curve. The screen voltage is 100 to ensure an adequate change of anode current being obtained by the variations of the grid signal voltages.

Filters.

As mentioned previously, a square topped signal can be represented by a Fourier Series, and relatively high frequencies contained in the wave would cause interference with neighbouring telephone circuits and apparatus. Furthermore as such signals are transmitted from the 2-wire terminals of a 4-wire amplified circuit, the higher frequencies will be transmitted over the speech circuit with comparatively low attenuation. At the receiving end these higher frequencies would recombine with the signals received over the phantom, but not, in general, in the correct phase, and thus would cause distortion of the signal received over the phantom. Also, on amplified circuits the high frequencies may cause heavy surges on the grids of the amplifying valves. Thus a low-pass filter at the sending end is desirable. Likewise at the receiving end a low-pass filter is necessary to exclude all but the essential impulse frequency range, and render the actual impulse receiver more immune from extraneous interference, particularly in view of the fact that phantoms of 4-wire Star Quad circuits are not balanced for phantom-to-phantom cross-talk.

Both sending and receiving filters pass up to 100 c.p.s. Although theoretically the insertion of low-pass filters should not appreciably affect the build-up time of the arrival curve, it will be appreciated that the inclusion of such filters will have a tendency to make the arrival and decay curves less steep. The filters consist of a series inductance and shunt condenser, forming an elementary low-pass filter. The performance of the filter will vary with line length, since at low frequencies the impedance looking into the sending end of the line will vary considerably with line length. Nevertheless, the arrangement is quite adequate to prevent any audio frequency dialling interference into other circuits.

Although at the outset it is proposed to use L.D.D.C. over amplified lines of 3 db. or more, it was considered desirable to arrange for 600 ohm terminating impedances over the audio range during the time the circuit is under impulsing conditions. The series inductance of the filter enables a 600 ohm termination to be presented to the line over the important audio frequency range at both sending and receiving ends.

C.R. Law.

It will readily be appreciated that the L.D.D.C. system may be called a Single Current Signal Shaping system, as the main requirement is a good wave shape of primary current, the maximum value being of no great consequence.

The reactive components of the line have considerable effect on wave shape, and the C.R. Law applied to a line states that " The time required to reach a stated fraction of maximum current at the receiving end is proportional to CRl^2, C and R being loop-mile constants in farads and ohms, l being length in miles." Thus the CRl^2 value of a line controls the signal shape.

The characteristics of Star Quad and Multiple Twin cables are considerably different in respect of mutual capacity value, while mixtures of these would be different again. Hence the impulsing limits of the L.D.D.C. system should not be referred to in terms of ohms. Again, owing to the difference in reactive components it is not strictly correct to speak of line lengths in terms of miles without specifying the type of circuit involved. Probably the most convenient general way of referring to these circuits is in terms of their CRl^2 values. On this basis the limits for satisfactory operation of the impulsing system is 75,000 μF. ohms, this being the equivalent of 100 miles of 20 lb. 4-wire Star Quad (phantom).

Primary Shunt.

This is shown as resistor PS in Fig. **7**. The terminating primary winding has an inductance of 2 Henries and at 60 miles and under of 20 lb. Star Quad 4-wire (phantom) the arrival and decay curves are oscillatory. Thus while the steepness of the wave shape is improved the oscillations induce secondary voltages which cause reverse signals to be applied to the grid of the valve as shown in Fig. **9**. Consequently the reverse waves AB and CD flow in the anode circuit. If the reverse current AB decreases to 5 mA, relay PR will prematurely operate to "Break," and if the reverse current CD reaches 15 mA (*i.e.*, 5 mA above nominal 10 mA) relay PR re-operates to "Make," thus giving rise to impulse splitting.

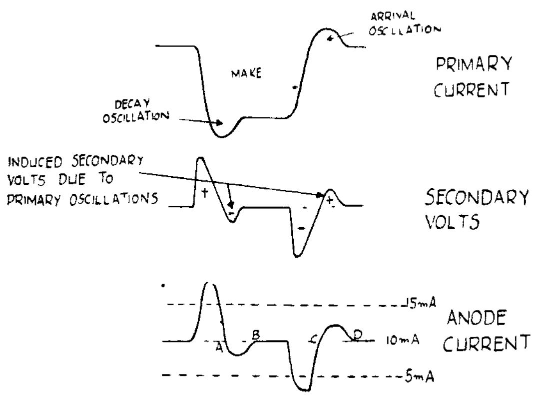


FIG. **9**.—OSCILLATORY CONDITIONS ON SHORT LINES.

As mentioned previously there is a relation between the time constant of the primary L/r and that of the line CRl^2 which gives best voltage wave shape, *i.e.*, approaching square top form. The primary current wave shape can be varied by varying the time constant of the primary by means of a N.I. shunt, and comparing the effects of high and low shunt values:—

High Shunt:

(*a*) Steep current rise in primary;
(*b*) peak anode current high;
(*c*) oscillation, if present without shunt, would still be present with high shunt.

Low Shunt:

(*a*) Gradual current rise in primary;
(*b*) peak anode current low;
(*c*) oscillation eliminated at the expense of the degraded wave shape.

Thus on short lines, with a steep current rise, but with the possibility of oscillation, the shunt must be low, and on long lines the shunt must be high. The ideal arrangement is obviously to obtain the same wave shape irrespective of line length, but this implies a separate value of shunt, for each line length, an undesirable feature. A marked degree of signal shaping is obtained by two shunt values adjusted as follows:—

CRl^2 of Line.	*Equivalent Line Length (20 lb. 4.W.P.C.Q.T. Phantom).*	*Shunt.*
0—42,000 μF. ohms.	0—75 miles	300 ohms.
42,000—75,000 μF. ohms.	75—100 miles	500 ohms.

It was considered that a CRl^2 range for shunt change over from 300 to 500 ohms was necessary to cater for normal errors likely to arise when calculating the CRl^2 value of a line; this is particularly important when the line is composed of sections of different types of cable. For this reason the above shunt values have been adopted so that the receiver functions satisfactorily from 0—60,000 μF. ohms with 300 ohm shunt and from 28,000—75,000 μF. ohms with 500 ohm shunt, so that the shunt change over range extends from 60—90 miles of 20 lb. 4-W. P.C.Q.T. cable. Thus satisfactory operation from 60—90 miles with either value of shunt is obtained.

The two settings of the shunt are obtained by a simple strapping scheme.

Fig. **10** shows the effect of 300 and 500 ohm shunts at 30 miles of 20 lb. 4-W. P.C.Q.T. and indicates the necessity for the 300 ohm shunt on short lines. Fig. **11** shows the effect on longer lines, indicating the necessity for the 500 ohm shunt in this case.

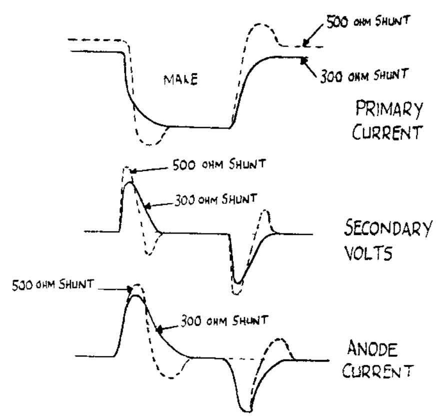


FIG. **10**.—RELATIVE EFFECTS OF 500 AND 300 OHM SHUNTS ON SHORT LINE.

5. FACTORS INFLUENCING IMPULSE DISTORTION.

In the following, positive distortion is assumed to be increase of make and negative distortion, decrease of make.

(a) Increased Break Period.

The break period from the Mechanical Impulse Regenerator can vary from 63—70%. As the break period increases the make decreases and the primary

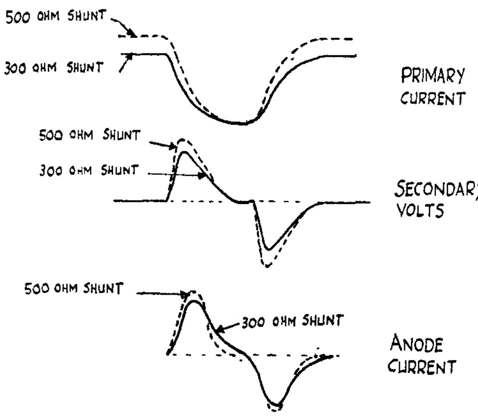


FIG. 11.—RELATIVE EFFECTS OF 500 AND 300 OHM SHUNTS ON LONG LINE.

decay and arrival curves tend to run into each other during the decreased make period. This is illustrated in Fig. **12**. During this period of mutual interference

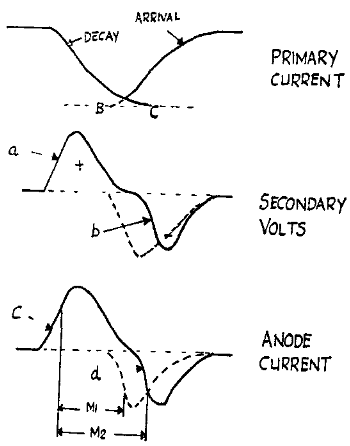


FIG. 12.—EFFECT OF MUTUAL INTERFERENCE BETWEEN ARRIVAL AND DECAY CURVES ON IMPULSE DISTORTION.

BC the decay current gives rise to a positive potential on the secondary and the arrival current gives rise to a negative potential. These induced secondary voltages tend to cancel out and the secondary wave " *b* " is retarded and made less steep, causing anode current wave " *d* " to be retarded. The result is that the make period is increased, giving positive distortion. The condition of mutual interference does not affect the steep front of the secondary wave " *a* " and anode current wave " *c*." The dotted secondary and anode waves in Fig. **12** are those to be expected when mutual interference does not occur, and it is readily seen that make period M2 is greater than M1.

Thus a long break period is the worst condition, and it will readily be appreciated that 50% break and make ratios would be of considerable advantage to the L.D.D.C. system.

(b) Increased Speed.

The speed of Mechanical Impulse Regenerators can vary between 9—11 I.P.S. As speed is increased, both break and make times are reduced, but the reduction in the make period is more important as this gives rise to mutual interference resulting in positive distortion as already discussed. The combination of short make and high speed is an adverse condition for the system.

(c) Increased Line.

The effect of increased line length is to reduce the maximum value of primary current, and to make the arrival and decay curves less steep. The secondary induced voltage waves are less steep and peak anode currents reduced. The polarised relay fails to operate to make when the anode current fails to reach 15 mA. Also, as the line length increases, there is a tendency towards mutual interference resulting in positive distortion.

(d) Incorrect Primary Shunt.

It has already been explained that on short lines the incorrect shunt (500 ohms) does not eliminate reverse waves caused by primary current oscillation, and this may result in impulse splitting. On long lines the incorrect shunt (300 ohms) results in gradual arrival and decay primary current curves and positive distortion.

(e) Anode Current Setting.

The nominal anode current setting is 10 mA with both main and positive batteries at 49 volts. As both these batteries may vary between 46 and 52 volts, the anode current will vary between 9 mA (with both batteries 46 volts) and 11 mA (with both batteries 52 volts). Fig. **13** shows typical anode current waves with anode current settings of 9, 10 and 11 mA.

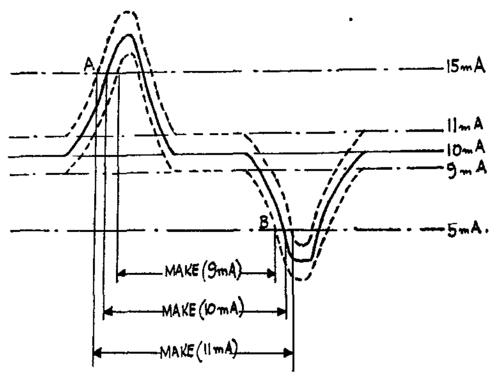


FIG. 13.—EFFECT OF ANODE CURRENT SETTING ON IMPULSE DISTORTION.

The polarised relay moves to make at 15 mA and to break at 5 mA (Fig. **8** refers). With high anode setting the current takes less time to build up to the operate to make (point A—15 mA) and takes longer time to decay to operate to break (point B—5 mA). Thus the make period is increased, giving positive distortion.

With low anode setting, the current takes longer to build up to point A and less time to decay to point B. Thus, referring to Fig. **13**, the make period at 11 mA is greater than that at 10 mA, that at 10 mA being greater than that at 9 mA. Thus reduction in anode current setting results in negative distortion.

(f) Varying Sending End Voltage.

In addition to 50-volt working, the system is designed for application to circuits outgoing from exchanges, where sending end voltages of 22, 24, 40 and 60 volts may be met, together with adverse voltage tolerances. Low sending end voltage is the greater concern as:—

(1) Maximum primary current is reduced.
(2) Primary arrival and decay curves are less steep.
(3) Induced secondary voltage waves are less steep and peak anode current is reduced.

Thus the system may fail at an earlier stage due to the anode current failing to reach 15 mA, resulting in the polarised relay failing to operate to make.

6. LINE LIMITS.

With L.D.D.C. 2-wire terminated equipment, *i.e.*, incorporating the impulse regenerator at the outgoing end, the line limits, determined with adverse impulsing conditions, are as follows:—

Sending End Volts.	*CRl² of Line (Micro-Farad Ohms).*	*Equivalent Length in Miles of 20 lb. 4-W. P.C.Q.T.*
30*	28,000	60
40	50,000	80
50	75,000	100
60	75,000	100

* 22 and 24 volt Exchanges.

The overall adverse impulse distortion of the above L.D.D.C. links is ±5%.

In addition to the L.D.D.C. links quoted above, a subsequent ordinary D.C. link of 800 ohms may be worked in tandem without impulse regeneration. Under practical conditions, when all factors influencing distortion would not be simultaneously adverse, it is confidently expected that this subsequent link can be increased above 800 ohms.

7. CIRCUIT PRINCIPLES

Having evolved a practicable D.C. impulsing scheme for application to long distance junctions and trunks, circuits must be devised to weld this new development into the existing network. The conversion of the ordinary make and break impulses into specially formed current pulses at the sending end of the circuit entails the use of an outgoing relay set in direct association with the junction, while at the incoming end, the junction must be terminated on a relay set capable of reconverting the impulses into their original form. The immediate requirements are therefore an impulse repeating relay set incorporating a signalling type transmission bridge at both ends of the junction.

With the ordinary type of impulse repeater, such as an auto-auto relay set, a considerable proportion of the impulse distortion is due to the mutilation of the impulse waveform by surges which pass in both directions across the transmission bridge condensers. As a result tandem working becomes somewhat problematical, but provided the recognised restrictions are adhered to in planning the area, satisfactory working can be obtained. If the L.D.D.C. outgoing and incoming relay sets were designed on the same basis, however, the mutilation of the impulse waveform would be far more serious. This fact was discovered during the early stages of development and various attempts to overcome this difficulty led to the conclusion that satisfactory working could not be obtained unless arrangements were made for isolating the impulse sending and receiving elements from the transmission bridges while impulsing is in progress. Furthermore it was found that the sensitivity of the impulse receiver is such that if it were permanently connected across the speech path, surges and tones fed back from subsequent switching stages would generate false impulses. Hence it soon became apparent that arrangements must be made in the incoming relay set for isolating the impulse receiving element from the transmission bridge from the moment the circuit is seized until all impulsing has been completed. Since this involves disconnection of the speech path the circuit must be restored to the normal condition in time for the caller to hear the ringing or other supervisory tones. This restoration, however, presents difficulties. The called subscriber answer signal occurs too late to be of any use, while the " end of dialling " signal, which is provided by restoration of the dial-key on a manual board, is not available when the junction is accessible from selector levels at the outgoing end. Hence, in the absence of a suitable indication as to which train of impulses is to be the last, arrangements must be made at the conclusion of the first impulse train, for the junction to be disconnected from the impulsing receiving element and re-connected to the transmission bridge. If this were the only train of impulses which had to be transmitted the problem would be simple, but before a second train can be received it is necessary to split the transmission bridge and re-connect the impulsing element to the junction once more. Normally no signal is available to indicate when the second or any subsequent train of impulses is likely to arrive, but such a facility can be provided by including an impulse storing and sending device in the outgoing relay set and arranging for it to send a " predialling signal " in front of every train of impulses.

A self-contained impulse storage and sending device was found in the Mechanical Impulse Regenerator. Of recent introduction, this piece of apparatus is compact and is designed to mount on a standard relay set plate.

The outgoing circuits have been developed around this Regenerator and in their final form have been separated into 2 relay sets which are associated by means of shelf jack strappings. The Regenerator Relay Set incorporates the Regenerator with its controlling relays and the sending end filter, while the Outgoing Relay Set includes the transmission bridge and supervisory relays together with means for passing the dialled impulses forward to the Regenerator. The design of the Outgoing Relay Set varies according to the mode of access to the junction, *i.e.*, whether from selector levels or from a Sleeve Control or Bridge Control manual board, but the Regenerator Relay Set is capable of working in association with any of these taken individually. Joint access facilities are not provided. The Incoming Relay Set incorporates the impulse receiving and repeating element together with a transmission bridge with supervisory and controlling relays and is permanently associated with an incoming first selector.

Signals.

With a view to preserving the electrical balance of the circuit and to minimise E.P.D. troubles while at the same time preventing mutual interference with other circuits, it is desirable that only loop signals should be passed over the junction between the terminal relay sets. It is also desirable that the signals used should as far as is possible have the same significance as in the standard automatic system. In satisfying the first requirement, however, it has been necessary to depart slightly from the latter. The circuit is seized initially by a loop condition applied at the outgoing end and the called subscriber answer signal is returned by a reversal of the junction polarity in the standard manner. The disconnection of the common with other equipment of recent design no provision is made for the repetition of busy flash.

Line Relays.

Before proceeding to a review of the circuit elements used in the signalling scheme just described, mention must be made of the problems connected with the use of telephone type relays for signalling on circuits of the length likely to be encountered at the maximum impulsing limit of the system. As mentioned previously the system was designed primarily for application to circuits carried in the 20 lb. Star Quad amplified cables and the limit in this case is equivalent to 100 miles of loaded line which has a loop resistance of approximately 4800 ohms. After allowance has been made for the resistance of the terminal equipment and the line relays themselves the available current is less than 5 mA, but 3000 type relays having a reasonable resistance can be designed to have the required sensitivity.

This sensitivity of the line relays LA, LB, D, IL and LS (Fig. 14) renders them extremely susceptible to

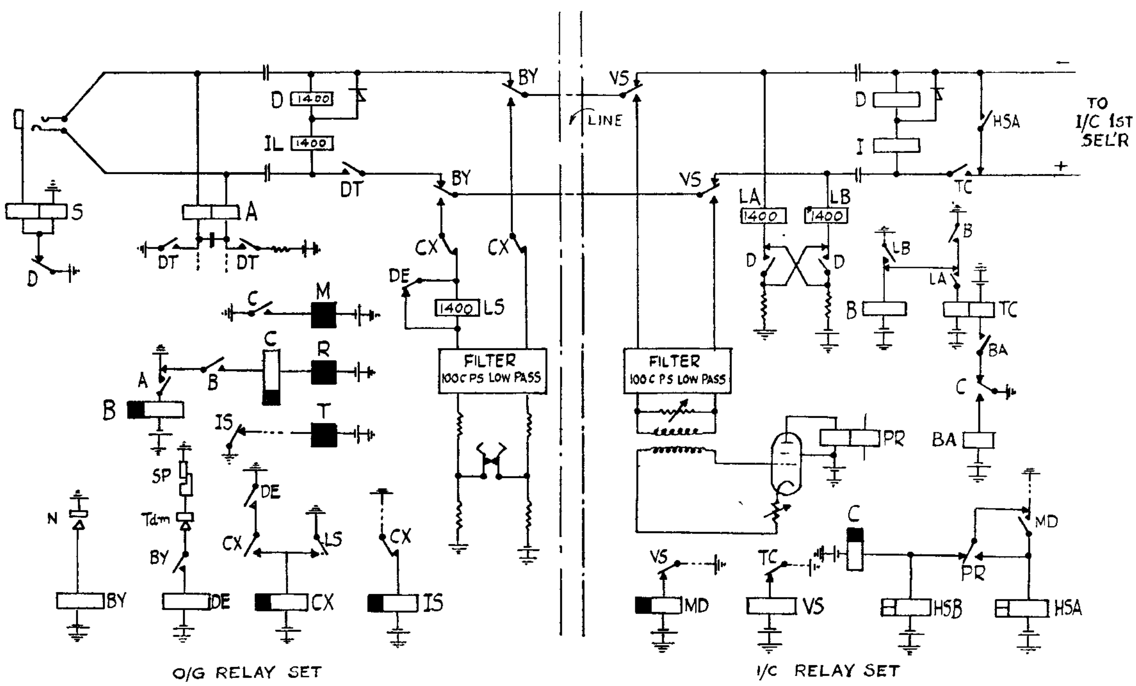


FIG. 14.—CIRCUIT ELEMENTS OF 2W. SCHEME SHOWING SEIZURE IMPULSING AND SUPERVISORY CONDITIONS.

holding loop at the outgoing end is used as a pre-dialling signal and does not cause the equipment at the incoming end to release. As no further convenient loop signals could be found a leg signal was introduced to give the indication of release to the incoming equipment, and, to effect the necessary discrimination in the incoming relay set, a separate signalling relay has been associated with each leg of the junction. The release of both line relays to the disconnection signal leaves the Incoming Relay Set held in the impulse receiving condition under the control of a local locking circuit, but when one of the relays LA is held operated and the other LB released the locking circuit is broken and the whole equipment restores to normal. In

the effects of the distributed line capacitance. Consequently their dynamic performance varies according to the length of the signalling circuit, while with a given length of line the performance of these relays is very much influenced by the amount of charge which must flow into or out of the line before the potential at any point can be changed. With the signalling system described the operating and releasing lags of the line relays may vary over a wide range. Furthermore, if the potential is suddenly changed on one leg of the junction the magnitude of the surge currents is sufficient to cause false operation of a relay associated with the other leg, while if a relay is suddenly applied to an uncharged line it will operate and retain until the junction charging current has died away. These unusual characteristics presented an interesting problem from the circuit design aspect and are responsible for certain novel features of the circuits.

Review of Circuit Elements.

The more important sequences concerned with the operation of a long distance D.C. impulsing circuit outgoing from a sleeve control manual board will now be reviewed. Fig. 14 shows in elemental form the arrangements for seizing the circuit, transmitting impulse trains, and returning supervisory signals. The circuit is marked " engaged " on the multiple jack and the F.L.S. relays are operated as soon as the plug is inserted into the outgoing jack, but the calling loop is not applied to the junction until the position dial key has been operated. The operator then dials a series of digits, the loop impulses being repeated by an impulsing relay to the Regenerator storage mechanism.

In the Regenerator mechanism the beginning of the impulse train is indicated by the energization of the marking magnet (M) which raises the radial marking arm clear of the storage pins. The impulses which constitute the train then cause the receiving magnet (R) to rotate the marking arm past the same number of storage pins. When the impulse train eventually finishes, the marking arm is released and displaces the storage pin over which it has been positioned by the incoming impulse train. Meanwhile the transmitting portion of the mechanism is held stationary by the mechanical engagement of the pin resetting plunger with the displaced storage pin that the marking arm has recently left. There is now a relative angular displacement between the sending and receiving portions of the mechanism and so long as any impulses remain stored this displacement persists and the off-normal springs (N) remain operated.

Hence at the outgoing end of the junction the splitting of the transmission bridge and isolation of the impulse sending element are conveniently controlled by the off normal springs. While these springs remain operated the junction is disconnected from the line signalling relays and transmission bridge and connected to the pulsing-out circuit of the Regenerator. The electrical contact (SP) between the pin re-setting plunger and the displaced storage pin, coupled with the operation of the off normal springs, now signifies that the Regenerator transmitting mechanism is at rest and is waiting to send a train of impulses. This condition, therefore, sets in motion the circuit sequences which control the transmission of an impulse train together with its pre-dialling signal and inter-digital pause period. These circuit sequences can best be described by assuming that the last impulse of a train has just been transmitted.

In the Incoming Relay Set a ' C ' relay of the normal type is releasing to indicate that the impulse train has finished, while in the Outgoing Relay Set this fact is indicated by the engagement of the resetting plunger with the next displaced storage pin (SP contacts). The ' C ' relay may have a release lag of up to 200 mS duration, so that it is impossible to switch the junction from the impulse receiving element back to the transmission bridge and line relays until at least 200 mS after the impulse train is finished. Since the line relays LA and LB must be connected and operated before the Incoming Relay Set can accept the next pre-dialling signal the transmission of this signal from the outgoing end must be delayed by a similar period. The required delaying action is achieved by placing the transmission of the pre-dialling signal at the outgoing end under the control of a relay (LS) connected in series with the junction, this relay being unable to operate until the battery and earth connected line relays are applied at the incoming end. Since the effect of the junction capacitance is now to speed up the operation of the relays at the incoming end while delaying the operation of the line testing relay at the outgoing end, there is no possibility of the pre-dialling signal being transmitted before the incoming equipment is ready to receive it.

When the holding loop is removed by the Regenerator Relay Set the junction capacitance charges to 50v. throughout its length with the result that the current flowing through the line relays in the Incoming Relay Set falls very gradually and may cause them to remain held for a further period of 250 mS. When these line relays eventually release the relief relay (B) associated with one of them remains locked to retain the circuit held, while the relief relay (TC) associated with the other line relay is released to operate relay VS and switch the junction from the speech to the impulse receiving condition. The charge previously stored in the junction is now dissipated in the impulsing circuit and to prevent false operation of the impulse repeating relays the circuit is masked during the release of a slow to release relay (MD), the minimum lag of which is designed to equal the maximum time likely to be required for the junction to reach a steady state. Thus, the Incoming Relay Set is not ready to receive the first impulse of a train until approximately 600 mS after the transmission of the pre-dialling signal. The Outgoing Relay Set therefore measures off by means of two slow-to-release relays (IS and CX) an interval of this duration between the beginning of the pre-dialling signal and the commencement of the next train of impulses. When the first of these slow relays (IS) releases, the transmitting magnet (T) is energised to break the Tdm. contact and depress the pin re-setting plunger which restores the displaced storage pin to its normal position, and when the second relay (CX) releases the magnet is released to withdraw the plunger and break the mechanical and electrical contact at this point. The transmitting mechanism then proceeds to send out a number of impulses corresponding to the number of pins over which the plunger passes before hitting against the next marked pin. The complete cycle of operations is repeated for every stored impulse train. The inter-digital pause is longer than that normally allowed between trains of Strowger impulses, since in addition to the 600 mS interval measured by the Outgoing Relay Set it includes the time required for the Incoming Relay Set to restore the line relay at that end together with the operating lag of the line testing relay at the outgoing end.

Fig. **15** shows in elemental form the arrangements for releasing the circuit.

Release of the connexion is achieved by disconnecting one leg of the junction while maintaining a holding condition on the other. Such a signal is unbalanced, but any interference it may cause on adjacent circuits retransmitted until the incoming equipment has completely released to remove the short-circuit and restore the battery and earth condition to the junction.

Normally, when the short circuit is removed and the line relays reconnected, the junction will be disconnected at the outgoing end and if the capacitance

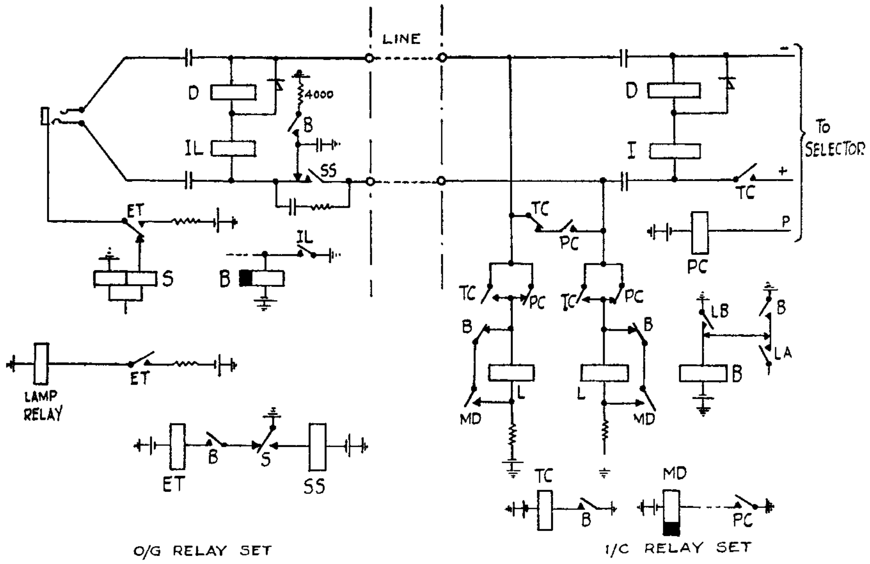


FIG. **15**.—CIRCUIT ELEMENTS OF 2W. SCHEME SHOWING RELEASE ARRANGEMENTS.

is minimised by the connexion of smoothing condensers across those contacts which are responsible for suddenly changing the potential of individual wires of the junction. The time required for the Incoming Relay Set and its associated selector train to restore completely to normal may exceed three seconds, but no attempt is made to guard the outgoing end of the junction against intrusion during the whole of this period. As soon as the release signal is received in the Incoming Relay Set the line relays at that end are both disconnected from the junction and replaced by a short circuit. This gives a signal to the outgoing equipment where the line relay (IL) in releasing causes the circuit to be unbusied and the release signal to be removed from the junction. Furthermore it guards the incoming equipment against reseizure since, although the follow-on call may cause impulses to be stored in the regenerator mechanism, they cannot be of the signalling path is large, heavy charging currents will flow at the incoming end. To prevent the line relays being operated falsely by such charging currents arrangements are made for them to be short-circuited until sufficient time has elapsed for the current to fall to a negligible value, this time being measured by the slow-to-release relay MD.

8. SIGNALLING ON 4-WIRE AMPLIFIED CIRCUITS.

Location of 2-4 Wire Terminations.

The L.D.D.C. impulsing scheme described previously can be applied to any type of circuit which provides the necessary metallic path. On a 4-wire amplified circuit the Outgoing and Incoming Relay Sets would normally be connected on the 2-wire side of the 2—4-wire termination, in which case the metallic signalling path is obtained as shown in Fig. **16**.

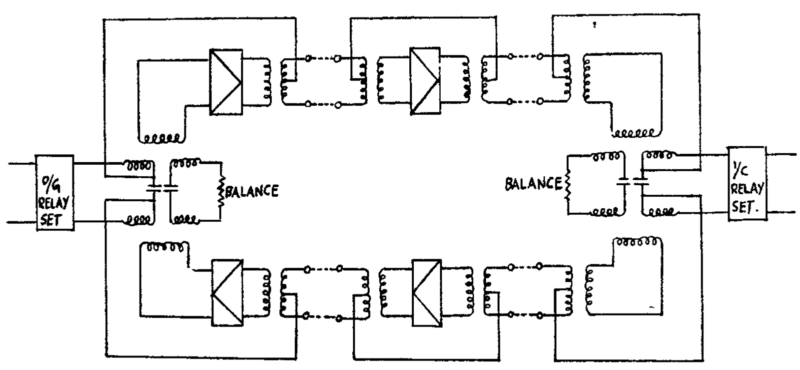


FIG. **16**.—4W. AMPLIFIED CIRCUIT—NORMAL CONNECTIONS OF SPEECH AND SIGNALLING PATHS.

The adverse effect of the series inductance and shunt capacitance of the hybrid termination on the signal shape has already been mentioned. When Outgoing and Incoming Relay Sets are employed in direct association with the junction as in the L.D.D.C. system these effects can be overcome by bypassing the signalling currents around the hybrid termination at each end of the circuit as shown in Fig. **17**. This scheme can, of course, be applied only where it is possible to extend the phantom circuit from the line transformers on the amplifier or line terminating rack to the I.D.F. by means of local tie cables or by means of a short extension circuit when the terminating equipment is located in a remote building. This arrangement gives in effect two segregated paths between the terminal relay sets, one, a 4-wire audio frequency path and the other a 2-wire phantom DC signalling path. In addition to the advantages gained from the L.D.D.C. impulsing point of view this " Segregated Path " method of working offers certain advantages from the speech transmission aspect.

(*a*) The elimination of the DC component from the 2-wire side of the hybrid transformer enables it to give an improved performance.

(*b*) The intensity of switching surges and other transients applied to the grids of the amplifier valves is considerably reduced.

(*c*) The injection of speech voltages, developed across the 1 μF. isolating condenser, into the unbalanced phantom circuit is avoided.

(*d*) Owing to the elimination of speech voltages from the unbalanced phantom circuits high gain amplifiers can be used in conjunction with Group worked cables.

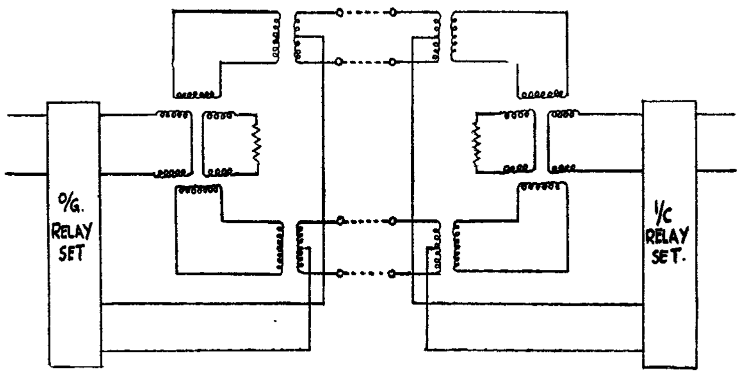


FIG. **17**.—4W. AMPLIFIED CIRCUIT—METHOD OF SEGREGATING SPEECH AND SIGNALLING PATHS.

Consideration of these points, together with the improvement in stability obtained when the 2-wire tail is made as short as possible has indicated the advisability of locating the 2—4-wire termination as near as possible to the terminating relay set. Manufacturing and other considerations prohibit the actual inclusion of the transformers in the signalling relay set, but in future the line terminating equipment will wherever possible be mounted on telephone type racks in the exchange apparatus room.

Four-Wire Terminated Circuits.

The arrangement shown in Fig. **17** offers other possibilities for preventing interfering voltages pro-

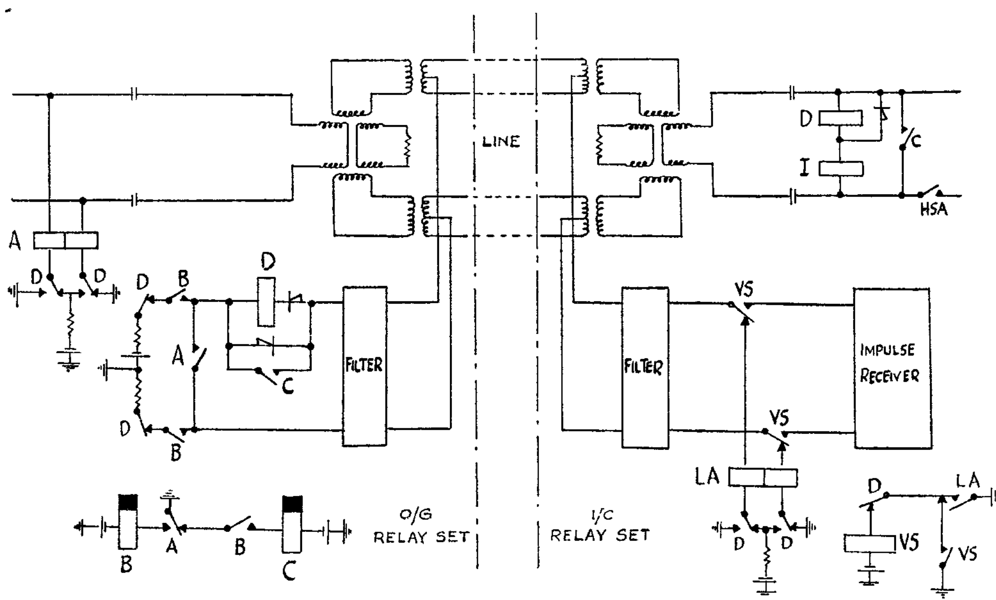


FIG. **18**.—CIRCUIT ELEMENTS—" 4-WIRE " SCHEME.

duced in the subsequent switching stages from influencing the impulsing element. Since the speech and signalling paths are completely and permanently isolated it is not necessary to disconnect the impulsing element at the end of each impulse train in order to restore the circuit to a condition in which it is capable of passing back tones, etc. The necessity for a pre-dialling signal and hence the need for an impulse storage device for sequencing purposes therefore disappears and it becomes possible to devise a scheme in which the amount of equipment is considerably reduced with consequent simplification of the circuit operation.

The essential features of such a straightforward scheme as applied to auto-auto working are shown in Fig. **18**. It will be seen that the loop seizure signal applied by the Outgoing Relay Set causes the Incoming Relay Set to lock and switch the junction from the line signalling relay to the impulsing element. Dialled impulses and movement of the caller's gravity switch are then repeated directly by the impulse receiver and if the caller clears before the call has been answered then a long " break " signal is transmitted to unlock the incoming equipment and releases the circuit. If a called subscriber answer signal is received before the caller clears the impulsing element is disconnected at the incoming end in order to allow the reversal signal to be returned over the junction. After this signal has been received in the Outgoing Relay Set the circuit can be cleared merely by disconnecting the junction holding loop.

It will be seen that this simplified scheme is applicable only to 4-wire terminated lines and for this reason is referred to as the " 4-wire " scheme. The more complex scheme employing regenerators may be used on 2-wire terminated or 4-wire terminated circuits, but since it is designed primarily for 2-wire terminated circuits it has for purposes of distinction been called the " 2-wire " scheme. It is important to notice that in view of the different significance of certain signals in the two schemes it is not possible to mix 2-wire and 4-wire equipment on the same circuit. The design of the two schemes has proceeded concurrently, and although both are arranged to provide the same facilities the cost of terminal equipment of 4-wire type is in all cases approximately 60% of that for the corresponding 2-wire equipment. The 4-wire scheme therefore has the advantage of being cheap as well as simple and robust.

The absence of an impulse storage device in the 4-wire scheme avoids the delays associated with such devices although, under tandem dialling conditions, it must not be forgotten that the storage device also has useful impulse regenerative properties. In this connection it should also be mentioned that the impulse repetition at the outgoing end of the 4-wire scheme introduces an additional distortion of $\pm 3\%$ which must be added to the overall distortion figures given previously.

9. ADDITIONAL FACILITIES.

Both-way Working.

By the addition of a simple Bothway Switching Relay Set the unidirectional outgoing and incoming equipments can be arranged to provide the following alternative types of bothway routes:—

(*a*) Auto to auto in each direction.
(*b*) Manual to auto in each direction.
(*c*) Auto to auto one way and manual to auto the other way.

Since the system is fundamentally a dialling system the bothway arrangements do not include facilities for working one way into a manual board termination, but should the need for this facility arise it can be provided. Certain elements for controlling the operations of the Bothway Switching Relay Set have been included in the outgoing and incoming unidirectional equipments at negligible cost, but all the complications of bothway working such as junction guarding and back-to-back working are catered for in the design of the Bothway Switching Relay Set itself.

Director Working.

A new type of First Code Selector has recently been designed for junction working. It incorporates a transmission bridge with through signalling facilities and is intended to interwork with existing ' A ' Digit

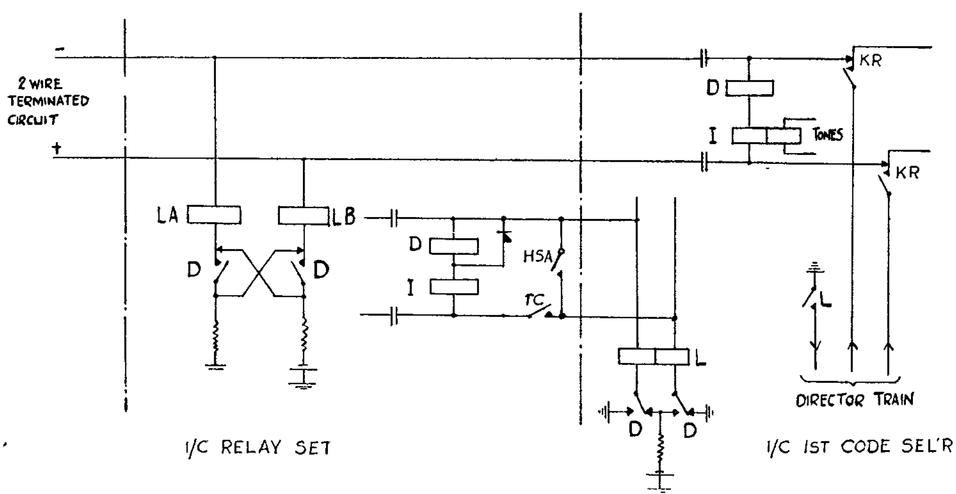
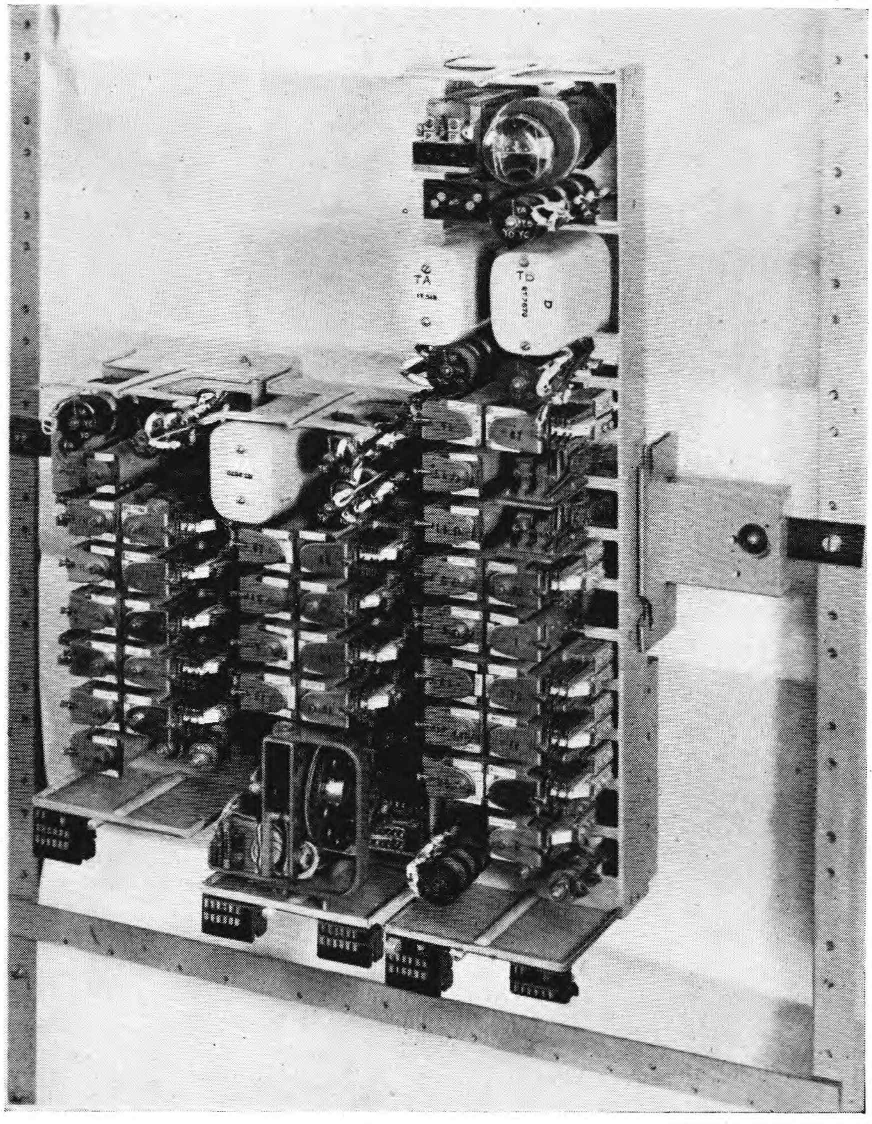


FIG. 19.—DIRECTOR WORKING—METHOD OF CONNECTING L.D D.C. I/C RELAY SET TO I/C 1ST CODE SELECTOR.

Selectors and Directors. When used on loop dialling circuits it will be connected directly to the junction, but when used on a Long Distance D.C. dialling circuit it will be connected *via* the Incoming Relay Set. Since the Incoming Relay Set and First Code Selector each contain a transmission bridge they cannot be connected in tandem in the normal manner, for fear of degrading the transmission, but the solution has been found by combining them as shown in Fig. **19**. Shelf jack straps enable the D. and I. loop of the Incoming Relay Set and the line relay of the First Code Selector to be divorced from their respective speech paths. The arrangement shown is suitable for 2-wire terminated circuits, but on a 4-wire terminated circuit the 2-wire side of the 2—4-wire termination can bypass the Incoming Relay Set by a direct connexion to the First Code Selector transmission bridge.

10. MAINTENANCE TESTING.

Since many instances will arise in which, at a particular exchange, all the L.D.D.C. circuits are either outgoing or incoming, separate testing equipments are being designed for these two groups of circuits. Outgoing circuits may possibly include a mixture of " 2-wire " and " 4-wire " equipment with both Auto-Auto and Sleeve Control relay sets, but in principle these circuits are very similar and one simple tester will cater for the different types. The only notable feature of this tester will be the arrangements for measuring the speed and ratio of the outgoing impulses. The new apparatus that is now being developed for the general application of these tests to mechanical regenerators is not yet available and in the meantime a dial speed tester in conjunction with a commercial moving coil milliammeter will be used.



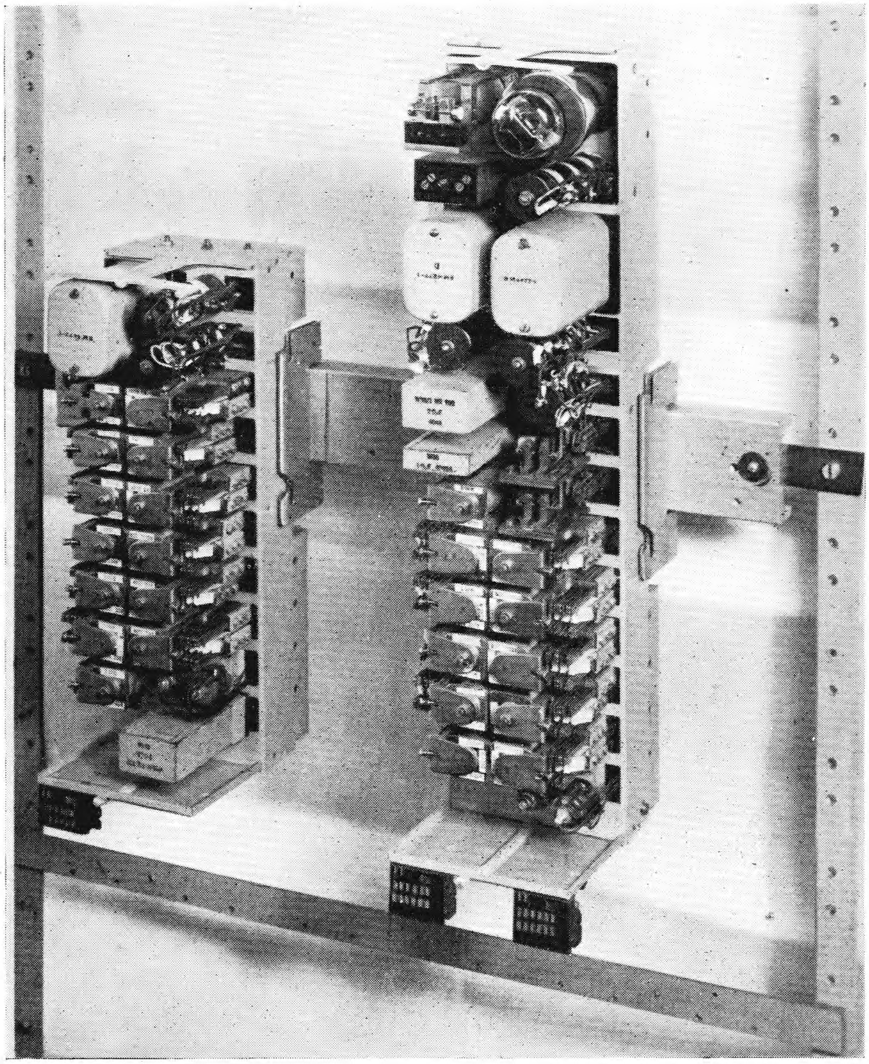
2-Wire Scheme.
Sleeve Control O/G Relay Set, Regenerator Relay Set and I/C Relay Set.

As far as the incoming circuits are concerned, they are also very similar, and one tester will cater for both "2-wire" and "4-wire" relay sets. The only special feature of this tester will be the apparatus provided for testing the impulsing element. A multi-range milliammeter-voltmeter movement will be used for measuring the anode currents, negative and positive battery voltages, and impulse ratio, while it will also be used for measuring the operating current required in relay PR for checking its adjustment. A cable simulation will be provided to enable the circuit to be impulsed locally and impulse ratio output of the receiver to be measured. It is thought that if any difficulty is experienced in connexion with the impulsing performance of a circuit these impulse ratio measurements will afford the quickest means of tracing the source of the trouble, while if such measurements are made as a routine matter they will indicate in a positive manner the quality of the service which is being given by the equipment.

11. FIELD TRIALS.

In September, 1938, the L.D.D.C. impulsing scheme was introduced experimentally between Belfast and Ballymena. The distance was short, being only 27 miles, but the circuits were of the 4-wire amplified type in a new 10 lb. P.C.Q.T. cable having a CRl^2 value of 12,000 μF. ohms. Unidirectional working was adopted, there being seven circuits in one direction and six in the other. Although the 2—4-wire terminations were in the same building as the exchange at each end of the circuit, for field trial purposes, the circuits were arranged as 2-wire terminated circuits, "2-wire" equipment of an early design being used. At both exchanges the L.D.D.C. incoming junctions were trunked in with other D/I traffic and had access to the same groups of outgoing junctions.

The equipment was built by the Department and functioned satisfactorily, requiring no modification or alteration. Traffic observations which were conducted during the early stages of the field trial gave the



4-Wire Scheme.
Sleeve Control O/G Relay Set and I/C Relay Set.

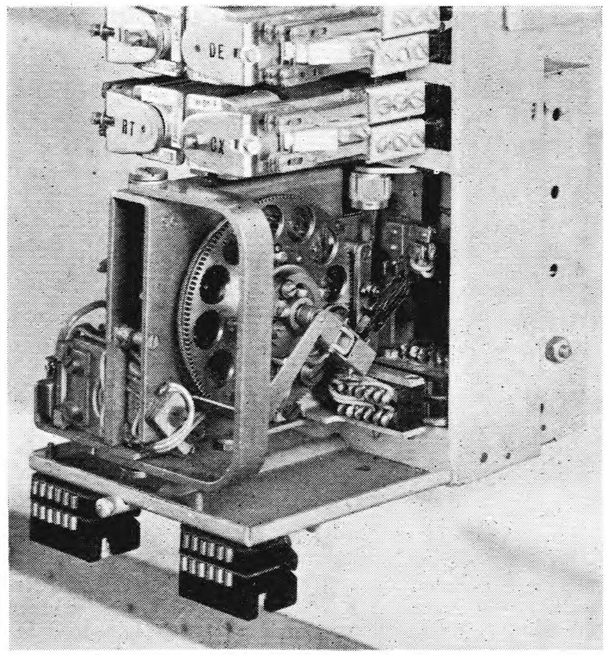
satisfactory figure of 99% O.K. calls. Favourable reports were received from the local Engineering and Traffic Staffs and when it was proposed to close down the field trial representations from these staffs led to a decision to leave the experimental equipment in service until it could be replaced by equipment of the standard design. Although the results of the field trial were negative in so far as they failed to disclose any fundamental weakness in the system, some interesting data on the reactions of the maintenance staff and on the question of valve performance was obtained. In 1938 the local engineering staff were only just becoming acquainted with automatic working, but they have been able to maintain this new system without difficulty.

The valves require readjustment of anode current at approximately yearly intervals, while a total useful life of two years is obtained in the majority of cases.

Field trials of short duration have also been conducted on lines of longer length, details of which are given.

For these experiments, which were conducted during 1939, equipment of the 4-wire type was used, the Outgoing and Incoming Relay Sets being mounted on self-contained transportable racks. Full dialling facilities were provided in one direction, outgoing from Birmingham, only, each route being taken in turn and the equipment put into service for the period required to permit a useful traffic observation to be made. Both the outgoing equipment located at Birmingham and the incoming equipment which was moved around as the trials progressed were continually under the care of the Engineer-in-Chief's staff, thereby enabling a useful check of the traffic observations to be made.

As would be imagined from the observation figures quoted these short trials were extremely successful and have proved conclusively the reliability of this new system.



VIEW OF MECHANICAL IMPULSE REGENERATOR.

Route.	*Route Mileage.*	*CRl^2 µF. ohms.*	*Type of Cable.*
Birmingham—Kettering ...	67.7	36,300	20 lb. P.C.Q.T.
Birmingham—Oxford ...	88	48,000	mixed 20 lb. and 25 lb. P.C.Q.T.
Birmingham—Cambridge ...	103	82,000	20 lb. P.C.Q.T.

Route.	*Traffic Sample.*	*O.K. Calls.*	*Faults due to L.D.D.C.*	*Type of I/C Exchange.*
Birmingham—Kettering ...	521 Calls	98.4%	0.6%	Self-contained ND.
Birmingham—Oxford ...	631 Calls	90%	1.3%	ND.
Birmingham—Cambridge ...	580 Calls	92%	1.0%	ND.

12. LINE PLANT LIMITATIONS.

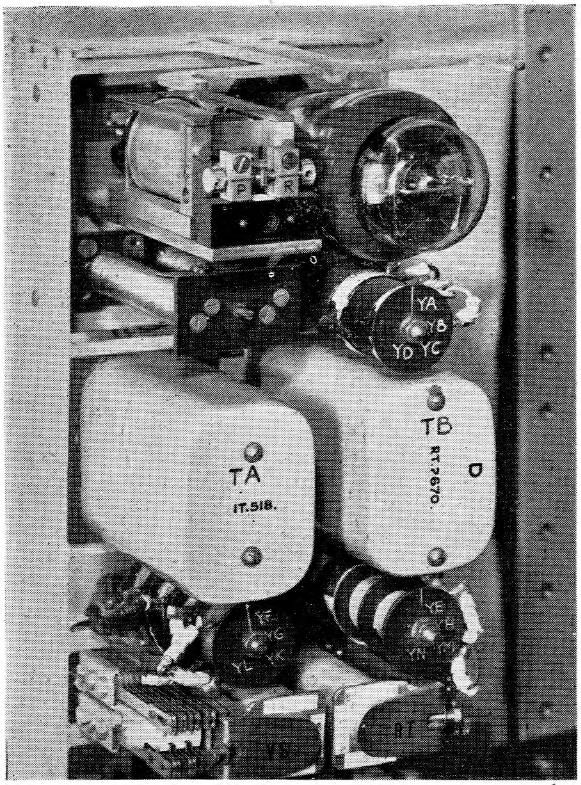
It has been pointed out previously that the L.D.D.C. system was designed primarily for application to the circuits carried in the new light gauge amplified cables. Application of the scheme to other types of circuits is of course subject to the limitations imposed by certain types of line plant. These limitations, which apply equally to most other forms of D.C. signalling, are:—

(a) Carrier Systems.

The absence of separate metallic paths prohibits D.C. signalling in any form.

(b) 2-Wire Amplified Circuits.

Earth return signalling is possible, but with loop signals there is considerable difficulty in obtaining a satisfactory bypassing circuit across the 2-wire amplifiers. Furthermore, direct currents flowing in the windings of the line transformers, and tending to produce saturation of the core, have adverse effects on the stability of the circuit.



I/C RELAY SET SHOWING VALVE AND POLARISED RELAY.

(c) Phantom Circuits.

Where phantom channels for speech are used it is not possible to employ D.C. loop signals on all circuits of a quad, but only on one or possibly two out of the three.

(d) Overhead Circuits.

Any system employing sensitive line relays cannot tolerate the inclusion of a section of overhead line which is likely to have an overall insulation resistance as low as 100,000 ohms.

In considering the ultimate effect of these limitations on the application of the Long Distance D.C. Dialling system one must visualize the inevitable extension of carrier working not only on the Z—G routes but on many G—G routes. Such visions are, however, well into the future and in the meantime many toll routes will continue to be carried in audio cables capable of providing the necessary paths for D.C. signalling. Furthermore, it seems likely that for some considerable time to come, there will be an economic lower junction length limit for carrier working which some authorities have put at about 50—70 miles. For junction routes shorter than this, audio cables of the light gauge 4-wire amplified type will continue to be laid for many years to come. Longer junction routes which are small both in size and in rate of growth will also continue to be carried on audio cables of the same type. Thus for the future the main limitations affecting L.D.D.C. dialling will be carrier working, but obsolescent obstacles such as phantom circuits, 2-wire amplified circuits and most overhead circuits are destined to disappear.

13. CONCLUSIONS.

A new system of D.C. impulsing and the circuits which have been built around it have been described. The system, although new in its application, is old in its conception in so far as signal shaping is based on certain recognised telegraphic principles, and the authors have every confidence in its reliability.

This new system is capable of fulfilling a generally felt want for an impulsing aid, where, as a result of a change from overhead to underground 4-wire amplified cable routing, a group of circuits becomes unsuitable for D.C. dialling by existing means, due to the limitations mentioned earlier, and without such an aid it becomes necessary to consider the withdrawal of dialling facilities.

Regarding the general application of the L.D.D.C. Impulsing system no definite programme has yet been formulated in relation to other methods of working. However, on account of the comparative robustness and cheapness of the system, and in view of the large proportion of the trunk and certainly the toll network which, at any forseeable future time, will be worked on an audio basis, a wide field of application of L.D.D.C. is presented.

In conclusion, the authors desire to point out that this paper would not be complete without reference to Mr. H. O. Ellis and Mr. W. H. B. Cooper, the originators of the scheme. The authors' grateful thanks are due to Mr. R. W. Gibson, of the Department's Circuit Laboratory, for his assistance during the field trials and laboratory investigations, and to Messrs. Standard Telephones and Cables, Ltd., for their co-operation during the development of the system and for their permission to reproduce the photographs.

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