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The Fundamentals of Direct Current Impulsing in Multi-Exchange Areas

S. WELCH, M.Sc.(Eng.), A.M.I.E.E.

A Paper read before the London Centre (Harrogate Group) of the Institution on 12th October, 1944, and at other Centres during the Session.

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CONTENTS.

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I. INTRODUCTION.

A clear understanding of the fundamentals of problems leads to a better understanding of the problem as a whole, and generally indicates the simplest and most logical methods of approach to overcome the difficulties. Direct current impulsing has a wide application in automatic telephony, and in this paper the fundamentals of this method of impulsing are examined. It is hoped that this fundamental method of treatment will meet the need of those who, while not intimately concerned with the finer technical details of D.C. impulsing phenomena, nevertheless desire an adequate basic knowledge of the subject as a whole.

Dialled telephone connections are built up link by link, and such routings require impulse repetitions at each tandem point. Each impulse repetition is a source of impulse distortion, and the paper discusses the factors which introduce, and new methods to minimise, this distortion. The long distance D.C. impulsing problem is examined as it may be necessary to apply such a technique to the local junction network in multi-exchange areas, and will certainly be required to facilitate dialling into such areas.

2. THE FUNDAMENTAL IMPULSING CIRCUIT.

In a multi-exchange area an auto-auto relay-set incorporating a transmission bridge is provided at the outgoing end of each junction, and arrangements are made for the impulses received to be repeated over the junction to the subsequent selectors. Fig. 1 shows the fundamental " loop dialling " impulsing circuit employing condenser type bridges, a subscriber on exchange A dialling a subscriber on exchange B.

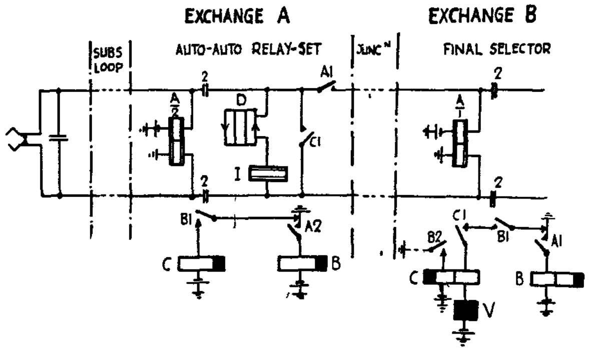


FIG. 1.—FUNDAMENTAL LOOP-DISCONNECT IMPULSING CIRCUIT. SINGLE JUNCTION CASE.

The impulsing consists of " making " and " breaking " a current by means of a contact, the make of the contact " looping " the line and the break " disconnecting " the loop at the transmitting end. Thus, a more appropriate term for " loop dialling " is " loop-disconnect " impulsing, and this term will be adopted for the purpose of this paper. It should be noted that infinite impedance (open circuit) is offered at the transmitting end during the period of disconnect.

The originating exchange equipment terminates on an impulse-receiving relay A, which, operating round the subscriber's loop, closes the junction loop to exchange B. The A relay at exchange A, responding to the impulses from the subscriber's dial, repeats the impulses to exchange B to operate the equipment at that exchange.

The C relays are required to hold operated during impulse-trains, and release at the end of each train. The B relays are required to hold operated during the complete impulsing period and not release until clear-down conditions obtain.

Considering the selector circuit, it is seen that the B relay is energised during the make period of contact A1, usually referred to as the " make contact closed period " (M.C.C.P.). The magnet and C relay are energised during the break period of A1, usually referred to as the " break contact closed period " (B.C.C.P.). Short M.C.C.P.'s cause failure due to (1) the B relay not receiving sufficient energisation to enable it to hold during impulsing, and (2) insufficient time for the magnet to release. This type of failure is usually known as " long (or non-leaky) line " failure. Short B.C.C.P.'s cause failure due to (3) the C relay not receiving sufficient energisation to enable it to hold during impulsing, and (4) insufficient time to operate the magnet. This type of failure is usually known as " short (or leaky) line " failure. The degree of distortion depends on the electrical characteristics of the medium over which the impulses are transmitted and the "faithfulness" of the repetitions. This will be discussed later, but for the present, it should be remembered that impulse-receiving relays associated with condenser bridges must be of high impedance to avoid undue speech loss, and the high self-inductance of such relays has a deleterious effect on the impulse repetition.

The A relay contact controlling the B and C relay circuits are of the " make-before-break " type to eliminate the effect of the transit time of the moving spring which occurs with " change-over " contacts.

Fig. 1 shows the pre-2000 type equipment impulsing circuit. That for 2000 type is virtually the same, except that the selector impulsing circuit incorporates short-circuited instead of slugged B and C relays.

3. IMPULSE REPETITION.

Impulses are repeated in each A-A relay-set and by each selector impulsing relay, and for the present purpose the term impulse repetition can be defined as " the reception at a given point of a number of impulses and their immediate transmission without storage." An efficient impulse repetition arrangement is one which will repeat, with minimum distortion, impulses transmitted over lines of various electrical characteristics, and the magnitude of the problem will be appreciated when it is realised that each characteristic has its own effect on the impulse waveform.

Considering the elementary loop-disconnect impulsing circuit, Fig. 2 and the resulting impulse wave-

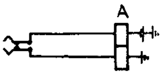


Fig. 2.—Loop-Disconnect Impulsing.

forms, Fig. 3, the A relay is fluxed for a period prior to impulsing, and on the first break the current dies away practically instantaneously. On the first make the current rises slowly due to the inductance of the relay. Due to eddy currents in the relay core, the flux lags behind the current waveform, as shown. The relatively long seizure condition results in a high initial flux value at the beginning of the first break, and the flux takes longer to fall to the release value P1. Between impulses, due to the inductance of the relay, the flux does not have time to build up to the same initial value, and on the second break the flux will fall to the release value P2 in less time than the initial fall to P1. Release lag R1 is thus greater than R2, giving rise to a type of first impulse distortion, the first break being shorter than subsequent breaks. It will be seen later that first impulse distortion is accentuated by condenser surges and the D and I relay circuit. Fig. 3 assumes that the relay operates and releases at the same current values on the line XY. This of course is not so in practice, as the current operate values of 3000 type relays are greater than the release values.

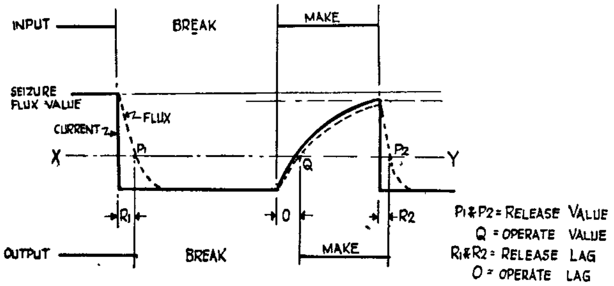


Fig. 3.—Current and Flux Waveforms—Loop-Disconnect Impulsing.

3.1 Effect of Line Resistance.

Line resistance reduces the flux in the impulsing relay and results in slower waveforms. One effect of this is to increase the operate time, and the lower the point on the arrival wavefront at which the relay operates, *i.e.*, the relay operating on a small fraction of the available current, the less the effect. The effect of eddy currents on the operate time increases rapidly with resistance, with the result that the relay operate time increases rapidly. As the maximum value of the flux is reduced, the release flux value is more quickly reached and relay releases quickly. Fig. 4 shows both these effects, and the rapid increase in the operate time should be specially noted.

The net result is that the break period increases (reference Curve A, Fig. 10), and conditions tend to failure of the B relay to hold during impulsing (long line failure). The effect is worse again on low volts.

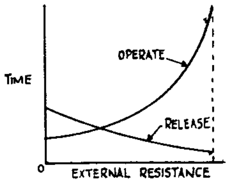


Fig. 4.—Effect of Resistance on Operate and Release Times.

3.2 Effect of Leakance.

Leak provides a current path to pre-flux the relay, and the operate time is reduced.

On release, there are three factors which tend to maintain the flux:—

(1) Eddy currents in the relay core.

(2) The impulsing battery circulates a current through the leak path.

(3) The leak functions as a non-inductive shunt, and the inductive discharge of the relay on break circulates via this path.

Fig. 5 shows the manner in which the relay flux decays on a leaky, as compared with non-leaky, line,

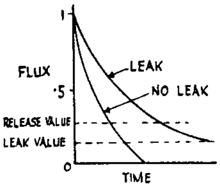


Fig. 5.—Flux Decay in Impulsing Relay on Leaky Line.

and it is readily seen that the release time of the relay will be increased. Fig. 6 shows the effect of the leak on the relay operate and release times, and the rapid increase of the release time should be specially noted.

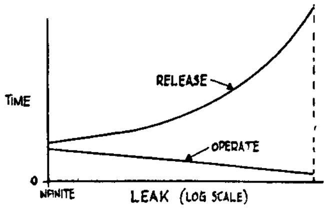


Fig. 6.—Effect of Leak on Relay Operate and Release Times.

The result is that the break is decreased and conditions tend to failure of the magnet to step and failure of the C relay to hold during impulsing (short line failure). Increased junction resistance will offset the effect of leakance, but this is not appreciable until the maximum allowable junction resistance determined by long line conditions is approached. Fast signalling speed (dial speed) is an obvious adverse condition on short leaky lines, more particularly when a number of short leaky lines are in tandem.

3.3 Effect of Condenser.

So far, consideration has been confined to a relay controlled by an impulsing contact. In practice, however, impulsing relays are frequently controlled by a contact across which is connected a condenser (spark quench). In addition, the bridge condensers in the A-A relay-set are connected across the impulsing relay, first by the D and I relay circuit, and later by the operation of the C1 contact. (See Fig. **1**.)

Consider first the condenser across the impulsing contacts. This condenser can have no influence on the operation of the relay except when a previous impulse has not attained the zero steady state condition. When the dial-springs open on break, the established magnetic field of the impulsing relay decays and generates an induced voltage of much higher value than the applied volts to charge the condenser to a higher voltage than battery. This initial condenser charging current is a damped oscillation, and the initial decay waveform does not fall as rapidly as that of the non-condenser condition. After the collapse of the flux in the impulsing relay, the condenser discharges its high voltage charge back into the relay and tends to set up a current of reversed polarity, as shown in oscillation DE, Fig. **7**. Resonance would make this very harmful, but this condition, does not arise with the usual values of C and L in circuit.

Thus, the effect of the condenser on short line is to decrease the break period, reference Curve B, Fig. **10**.

Considering the relay itself, eddy currents, hysteresis loss and saturation of the core have a considerable damping effect on the free oscillation.

Fig. **7** shows the nature of the decay waveform under short line conditions. The oscillation DE may operate the relay in the reverse direction to give rise to split impulsing if the magnet is sufficiently sensitive or the oscillation appreciable. On the other hand, the magnet may receive an energisation AB which, while not sufficient to operate it, will shorten the effective energisation time by period AC.

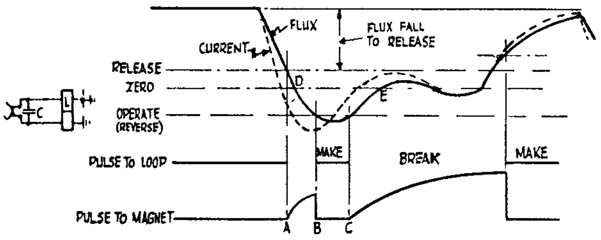


Fig. 7.—Effect of Condenser Across Impulsing Contacts (Zero Line).

With no condenser in circuit, it has already been shown that increased line resistance increases the break period. This effect will offset the decrease of break due to the inclusion of the condenser, the net effect being dependent on the relative values of R, L and C. The inclusion of R has a damping effect, and the tendency to reverse oscillation is reduced. The compensating property of R will continue with increasing line resistance resulting in less overall distortion until the line resistance becomes so great that the flux has only a small way to fall to the release point (compare Figs. **7** and **8**) and this outweighs the fact that it is falling slowly. Thus, at high values the effect of R predominates and the release time of the relay becomes short again and the break begins to increase (Curve B, Fig. **10**).

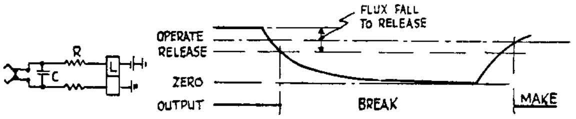
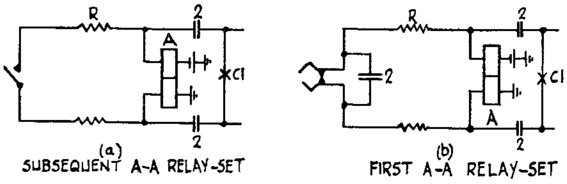


Fig. 8.—Effect of Condenser Across Impulsing Contacts (Long Line).

Now consider the effect of the transmission bridge condensers. When the C1 contact operates, the condition shown in Fig. **9**(*a*) applies, a 1 μF capacitance being connected directly across the relay. The current cannot rise in the relay on make until the bridge condensers commence the partial discharge, the relay operate lag is increased and the break period increases. On break the bridge condensers charge, partially, to the potential of the battery behind the impulsing relay and this delays the release of the relay and decreases the break. This tends to offset the increase of break due to discharge of the bridge condensers when the relay is operating on make. The magnitude of the bridge condensers' partial charge and discharge is dependent on the relative values of the impulsing relay and line resistances, the charge (and discharge) increasing as the line resistance R decreases. Curve C, Fig. **10**, shows the net result with increase of R, the increase of break being due, in the main, to line resistance, but it should be noted that the increase of break is not so rapid as when the bridge condensers are not present (compare Curves A and C, Fig. **10**). This condition represents the second and subsequent A-A relay-sets in a tandem connection. The conditions for the first A-A relay-set are shown in Fig. 9(*b*), where R is the resistance of the subscriber's loop and a 2 μF condenser is connected across the dial springs, the total capacitance being 3 μF. In these conditions the net result is that the break period tends to decrease slightly up to the maximum permissible value of subscriber's line resistance which is usually less than that of junctions.



(a) SUBSEQUENT A-A RELAY-SET

(b) FIRST A-A RELAY-SET

Fig. 9.—A-A Relay-Sets—Condenser Conditions.

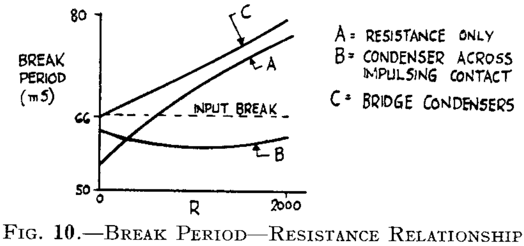


Fig. 10.—Break Period—Resistance Relationship.

3.4 Effect of Leak and Capacitance.

The leak has a complicated effect when a condenser is present across the impulsing contact, for, while the leak enables a retaining current to flow, causing the relay to tend to hold, it also reduces the peak voltage across the condenser. Owing to the oscillation produced by the condenser, the relay will still have approximately the same release time with a moderate leak as with none, for the reverse period of oscillation will cancel the retaining current flowing through the leak. Thus, the leak reduces the effective size of the condenser. As the leak increases, however, it tends to make the circuit less oscillatory, and a point is reached where the circuit is not sufficiently oscillatory to enable the relay to release quickly, and the break period tends to decrease.

As the main effect of leak is to delay the release of the relay and to decrease the break, the use of a condenser is beneficial to a certain degree, as it renders the release time more independent of leak. As mentioned above, however, there is a limit to the amount of leak permissible, and when this value is exceeded the break decreases rapidly.

Fig. **11** shows the flux decay waveforms under the various conditions of condenser and leak, and it is seen that the condenser plus leak waveform is more gradual than that of condenser only, to give decreased break.

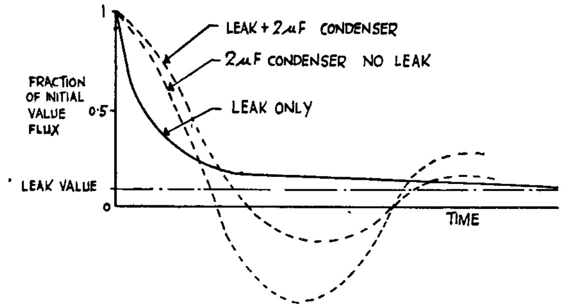


Fig. 11.—Flux Decay Waveforms—Impulsing Relay on Leaky Line with Condenser Across Impulsing Springs.

3.5 Effect of Relay Performance Variation.

A relay can only reproduce distortionless signals if the operate and release lags are equal, the only effect then being that the output is displaced in time from the input by the operate time of the relay.

From the previous sections it is evident that the various electrical characteristics of the line have considerable effect on the impulsing waveforms. These differing waveforms give rise in turn to varying degrees of impulse distortion, in a negative or positive sense, depending on the relay operate and release times. Fig. **12** shows typical waveforms of a relay on a simple resistive line ; the arrival waveform is shown to be more gradual than the decay. Now assume the relay operating and releasing at the same current value, it is clear that the release lag will be less than the operate lag resulting in increased output break.

In addition to varying waveforms, however, variations in relay performance have considerable effect on the operate and release times. In practice, the operate current values of 3000-type relays are higher than the release values. Referring to Fig. **12**, suppose the relay releases at B and operates at B1, this results in an output break B greater than the input break. Now suppose the relay springs are in heavier tension, the relay releases earlier at point A, thus reducing the release time, and operates later, at point A1 to increase the operate time, and output break A is greater than output break B.

Impulse distortion is thus the difference between the operate and release times of the relay. This is shown in Fig. **12** where the output break B is greater than the input break by the time the operate time 0 exceeds the release time R. It is obviously good practice to ensure maximum rate of change of current about the operate and release points, as this minimises the effect of relay variations.

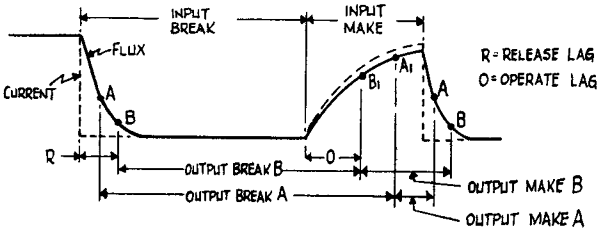


Fig. 12.—Effect of Relay Variation.

3.6 First Impulse Distortion.

First impulse distortion due to the higher flux in the relay before the first break has already been discussed. Another cause of first impulse distortion arises from the operation of the C1 contact during the first break. From Fig. **1** it is seen that on A-A relay-set junctions, during the make condition prior to impulsing, and during part of the first break, the back side of the bridge includes the D and I relays in circuit (ref. Fig. **13***c*) and during the make condition prior to subsequent breaks the back bridge is short-circuited by the C1 contact (ref. Fig. **13***d*). This means that the first break is transmitted under different conditions from subsequent breaks, and considering the case of second and subsequent A-A relay-sets, two effects are produced:—

(1) Retardation of the first release of the A relay due to the D and I relays in the same bridge.

(2) Prior to the first release, the impulsing relay is energised in a circuit which includes the D and I relays of the preceding relay set in addition to line resistance, whereas previous to subsequent breaks it is energised through line resistance only. This has an opposite tendency to (1), and tends to make the first break longer than others by allowing the relay to release quicker.

Considering effect (1) in further detail, on the first break, the high impedance D and I relays are connected across the back bridge, and the high impedance impulsing relay across the front bridge (ref. Fig. **13***c*). Before the first break, the bridge condensers have attained steady potential, and during the first break the current in the impulsing relay decays at a relatively slow rate in the form of a highly damped oscillation, the actual waveform depending on the initial and final states of charge of the condensers and the inductance of the A, D and I relays. On subsequent breaks the back bridge is short-circuited and the decay waveform in the relay is less highly damped, resulting in quicker decay and increased break. Thus effect (1) gives rise to short break on the first impulse.

Although effect (2) tends to offset (1), the latter predominates and the first break is reduced, being still further reduced as the number of tandem links is increased.

The conditions for the first A-A relay-set are shown in Fig. **13** (*a*) and (*b*), the essential difference being that the subscriber's loop precedes the relay-set and a condenser is connected across the dial springs. The increased capacity results in increased oscillatory tendency of the circuit and relay A tends to release quicker. The net result is that the first and subsequent breaks are about equal.

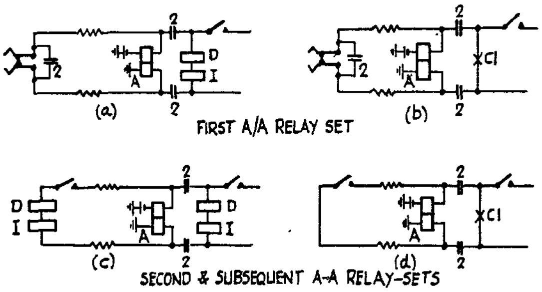


FIG. 13.—FIRST IMPULSE DISTORTION—CIRCUIT ELEMENTS.

4. SURGES—CONDENSER BRIDGES IN TANDEM.

Section 3 discussed the effect of line characteristics and relay variations on individual impulse repetitions. On tandem connections with condenser type transmission bridges, however, the problem is complicated further by the surge path provided by the line condensers.

During impulsing, the potentials across the line condensers are subject to violent changes due to altering circuit conditions and to the induced potentials from the relay coils. With each change of potential, currents flow through the line condensers and pursue various paths through the impulsing relays. The action of the relays is therefore not dependent only on the conditions obtaining in their own section of line, but is effected also by the conditions obtaining in the adjacent sections. For this reason each section of line cannot be considered as a separate entity, nor is it correct to assume that the signal received over one section is merely passed forward to the next section by simple relaying action. With several transmission bridges in tandem, the conditions are more complicated, since the effect from the first may pass through all succeeding bridges and become added at each stage. For this reason impulsing performance cannot be predicted over tandem connections with condenser bridges. A further difficulty is the type of impulsing relay. For impulsing, a relay having the smallest possible inductance and storing the least possible energy is obviously desirable. In condenser bridges, however, the relay is required to be high impedance for speech transmission purposes, and therefore of high inductance. Such a relay cannot be expected to give really good impulsing performance.

Complete analysis of the various surge effects would be lengthy and complicated, and will not be attempted. To explain the general effect it will be necessary to reiterate the various surge phenomena already discussed.

Consider the A-A relay-set preceding the first junction ; when the dial contacts open on first break, the instrument condenser charges in series with the impulsing relay, and at this instant the relay is directly coupled to the junction by the line condensers. These conditions result in an oscillatory surge through the impulsing relay, and tend to delay its release. On break of the A contact in the forward loop, another surge is transmitted through the line condensers, and this is followed by a further surge when the C relay operates to short-circuit the inductance of the D and I relays. A surge also occurs when the dial contacts make at the end of the break pulse.

In a similar manner surges are generated at all A-A relay-sets by the opening and closing of the impulsing and C relay contacts.

The surges may be divided into those which travel along both wires of a circuit in the same direction in parallel returning via earth (longitudinal surges) and those which follow the loop circuit formed by the two wires (transverse surges).

Transverse surges are suppressed by the operation of the C relays at each tandem point, and during impulsing the effect of these surges is thus limited to the first break and to the relay in the link following the link on which the surge occurs. In condenser bridges this surge is large enough to have an effect. The nature of the coupling between the input and output sides of the condenser bridge is such that longitudinal surges are transmitted so that the impulse wave-shapes on one link are modified by the switching condition on all the others, and, should this modification occur when the relay is about to operate or release, impulsing is affected.

These surge phenomena are one of the serious objections to the use of condenser type transmission bridges for impulsing purposes.

5. B AND C RELAYS AND MAGNETS.

The ranges of subscribers' and junction lines over which satisfactory impulsing is possible are based on the capacity of selector magnets and B and C relays, when at the permissible adverse limit of reasonable adjustment, to withstand distortion of impulses at the limiting dial speeds obtaining in practice.

The performance of the B and C relays is based on a ratio condition, while that of the magnet is a time condition only.

The A-A relay-set C relay is non-pre-operated, and is energised during the break period. At the first break the flux rises rapidly to operate the relay, and at the end of the impulse the flux decreases until the beginning of the next break. At the beginning of the second energisation, there is a flux in the relay core and a current in the slug. The battery will circulate a current tending to increase the diminishing flux, ana thus the slug current must reverse in direction. This reversal will not be instantaneous. The flux will rise to a higher value at the end of the second impulse, and the resultant saw-tooth Flux-Time curve (Fig. **14**) gets higher on successive impulses, the curve being of logarithmic nature. It will be noted that the danger period for relay release is at the end of the first impulse, *i.e.*, at Φ_2.

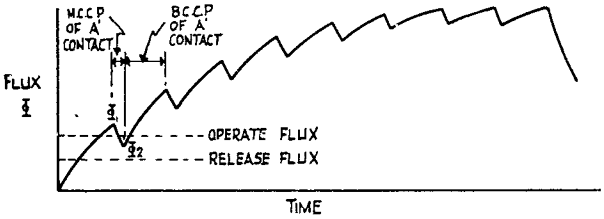


Fig. 14.—Flux-Time Curve During Impulsing Non-Pre-Operated C Relay.

The superiority of a relay having a short-circuited winding closed by a make contact to obtain the slow release feature, over a relay with a slug, lies in the fact that here the rate of rise of flux before operation is great. The early part of the curve is considerably raised, and there is much less chance of premature release.

Now consider the pre-operated B relay. The Flux-Time curve is shown in Fig. **15**, and here the risk of failure is at the end and not at the beginning of the impulse train. After a time, and providing the impulse ratio is suitable, the lower part of the saw-tooth curve will not fall below the release flux value, and the relay will hold for an infinite number of impulses.

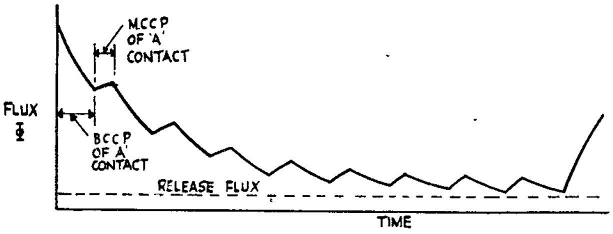


Fig. 15.—Flux-Time Curve During Impulsing Pre-Operated B Relay.

With selector pre-operated C relays, the flux decreases during the make period and increases during the break.

It is clear, therefore, that the satisfactory performance of B and C relays is very much dependent on the impulse ratio and dial speed.

6. "PICK UP."

Impulsing limits are not always limits determined by actual impulsing performance. While at first sight this statement may appear to be rather paradoxical, it should be appreciated that other signalling operations, in addition to impulsing, must occur before a connection is set up. A limit may be dictated by any one of these signalling conditions, although actual impulsing may be possible over a greater limit. In general, it may be said that one of the following factors may determine the "impulsing" limit:—

(*a*) Pick up.

(*b*) Impulse distortion.

Generally (*a*) determines the limit for individual junctions on tandem connections, and (*b*) limits the overall junction resistance on tandem connections.

The term "pick up" is used to describe a change of signalling condition between equipment in tandem, and is qualified to indicate the specific condition. Before proceeding to discuss pick up phenomena, it should be borne in mind that the A-A impulsing relay has a heavier spring load than the selector relay, and consequently has higher operate and release current values.

6.1 Initial Pick Up (I.P.U.).

This occurs when subsequent equipment is initially picked up (or seized) by an A-A relay-set. Two instances arise:—

(*a*) When the loop at the A-A relay-set is completed to seize a distant selector.

(*b*) When an A-A relay-set seizes a subsequent A-A relay-set. This condition may accentuate the difficulties resulting from (1).

On operation of the A-A impulsing relay, the line is looped to the subsequent selector A relay which is required to operate as quickly as possible to this initial pick up condition. From Fig. **16** (*a*) it is seen that the pick up circuit consists of the A-A D and I relays, the line and the selector A relay. High line resistance combined with the high total inductance of the circuit causes the arrival wavefront to be extremely gradual and the relay operates slowly. In consequence, the A relay K contact "bunches" for an appreciable time, and if the B and C relays operate, a pulse is given to the selector magnet tending to cause a premature vertical step.

Depending on the adjustment of the selector A relay, a number of pulses may be given to the vertical magnet without necessarily operating the magnet, as, when the A relay moves slowly, the momentum of its moving parts is low and the armature tends to drop back again when it takes the whole load, and then tends to re-operate to repeat the process.

The possibility of premature selector step may, in certain circumstances, be further accentuated should a preceding junction be long enough to cause the A-A A relay to operate slowly, for when this occurs the A-A C relay may operate momentarily during the " bunching " period, and when the C1 contact (see Fig. **1**) again releases on complete operation of the A-A A relay, the D and I relays are introduced into the selector pick up circuit to cause a surge to pass down the line to de-energise the selector A relay. If the selector B relay has been operated this surge release may cause a premature selector step.

The worst initial pick up condition arises on the single junction impulsing case, as this junction is long compared with the usual loop-disconnect tandem junctions. The adverse conditions for initial pick up are low volts, high line resistance, " light " magnet, " heavy " A relay, " light " selector B and C relays, large D, I and A relay inductance, and, depending on the incidence of these adverse conditions, premature vertical step may occur on junctions less than 1500 ohms. Impulsing might be possible over junctions of greater resistance, and then initial pick up would determine the " impulsing " limit.

The large D, I and A relay inductance is the main factor contributing to the slow rise of current, and a reduction of this inductance would result in appreciable improvement. This has been accomplished by connecting a rectifier across the line winding of the D relay. Fig. **16** (*b*) shows the arrangement, and it is seen that the inductance of the D relay has been eliminated under the initial pick up condition, the circuit now being completed via the forward resistance of the rectifier MR. The D relay retains its unidirectional operating feature. This arrangement permits an initial pick up junction limit of 300 ohms greater than that permitted by Fig. **16** (*a*).

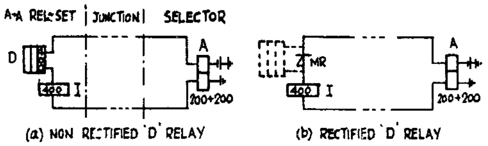


FIG. **16**.—INITIAL PICK UP—CIRCUIT ELEMENTS.

Fig. **17** shows a typical curve relating bunching time of the selector A relay and junction resistance for both the rectified and non-rectified circuits, and shows the extent of improvement afforded by the rectifier. The contact clearance of the selector A relay K contact has a great effect on initial pick up, as this varies the mechanical state of the springs to give greater or less bunching time under otherwise equal conditions.

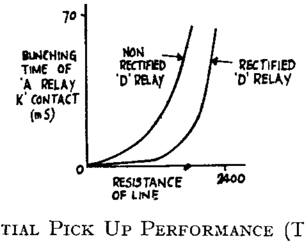


FIG. **17**.—INITIAL PICK UP PERFORMANCE (TYPICAL CURVE).

Initial pick up trouble is more prone to occur on long amplified lines as the time constant of the line itself results in a gradual arrival wavefront which is further retarded by the inductance of the relays.

Initial pick up difficulties do not arise with the 2000-type selector impulsing circuit, as circuit arrangements prevent the C relay operating during the bunching period.

6.2 Subsequent Pick Up (S.P.U.).

This occurs when the A-A relay-set drops back from the impulsing to the holding condition at the end of each impulse train. Two instances arise:—

(*a*) Between two A-A relay-sets.

(*b*) Between an A-A relay-set and a selector.

Fig. **18** shows the circuit elements concerned for case (*a*).

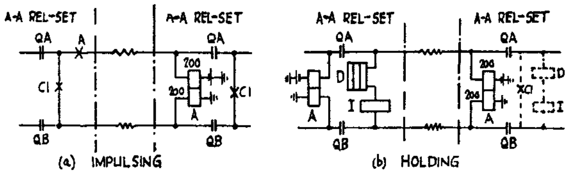


FIG. **18**.—SUBSEQUENT PICK UP—IMPULSING AND HOLDING CIRCUIT ELEMENTS—INTER A-A RELAY-SET JUNCTION.

At the end of a train of impulses, the A-A C relay releases and the D and I relays are introduced into the A relay holding circuit (Fig. **18** (*b*)). The D and I relays are not fluxed when they are introduced into the circuit, with the result that at this instant the D and I relay path must be regarded as of infinite impedance, and the holding current of the A relay will drop momentarily to zero, tending to release the relay and give an extra impulse to the subsequent selector. Another effect is the setting up of a condenser surge due to the sudden introduction of the D and I relays. At the instant of introduction a current will flow to raise the potential of the A-A relay-set bridge condensers, and this current simply delays the fall of current in the A relay. As the current rises in the high impedance D and I relay circuit, the potential difference across the bridge condensers is reduced and they commence to discharge, partly via the high impedance circuit to assist the current rise in the D and I relays, and partly via the A relay to oppose the current in this relay. The surge may be of sufficient magnitude to result in negative ampere turns in the A relay. This relay tends to release to give a false impulse to the selector ahead. The effect is dependent on the C relay release lags in the relevant A-A relay-sets. It must not be assumed, however, that it is this condenser discharge alone which causes the false impulse, but rather the introduction of the D and I relays causing the condensers to discharge momentarily to emphasize the fall of current in the A relay.

Whether the extra step is vertical or rotary depends on the relative release lags of the A-A and the selector C relays. If the A-A C lag is short, the extra step will be vertical, and if long, the selector E relay may have operated and the extra step will be rotary.

The A-A A relay is more heavily loaded than selector A relays, and tends to release earlier ; consequently the worst form of S.P.U. occurs between two A-A relay sets. Here it is also possible for the selector A relay to flick in addition to the second A-A A relay, and the final false step may therefore be caused by a series of impulses varying in degree. In practice, conditions are modified by varying line resistance, high resistance being onerous, as the A relay current need only fall slightly to reach the release value, and also the subsequent current increase is slow, which tends to permit the A relay to be released for sufficient time to operate the magnet.

S.P.U. (non-ballast equipment) is largely mitigated by a rectifier across the D relay, *i.e.*, the same rectifier (Fig. **16** (*b*)) included for improving the I.P.U. performance. This rectifier causes an increase in the final value of current when the C relay releases and reduces the effective inductance of the circuit by eliminating the effect of D relay inductance so that the oscillation set up in the A relay is of smaller amplitude.

Due to the lightly loaded selector A relay, S.P.U. is no real difficulty with single junction impulsing. With tandem working, however, an extra impulse can be given when the A-A relay-set junction is 500 ohms (non-rectified circuit) ; the rectifier across the D relay can increase the limit to about 1000 ohms.

6.3 Called Subscriber Answer Pick Up. (C.S.A.P.U.)

Of all pick up effects C.S.A.P.U. introduces the most severe limitation. The current reversal signalling the answer condition occurs behind the A-A A relay and the flux in the relay has to reverse. This reversal occurs after the impulsing operation, and, assuming the I.P.U., impulsing and S.P.U. limits to be such that the A relay has just sufficient flux to function, or to function with little factor of safety, the flux reversal will cause the A relay to release and remain released. This is due to the remanence effect not allowing the flux in the reverse direction to build up to the same value as in the first direction, so that for the relay to pick up fully the junction resistance has to be reduced.

C.S.A.P.U. limits inter-A-A relay-set junctions to 800 ohms, and it is seen that this is 200 ohms below the limit determined by S.P.U. conditions (rectified D relay case).

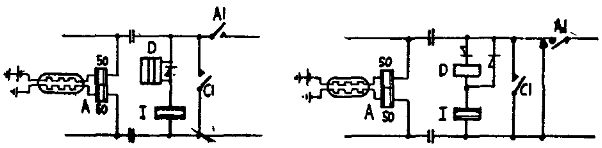
The current reversal from the final selector occurs in front of the A relay, and consequently does not introduce any limitation in the single junction circuit or in the last link of a tandem connection.

7. BALLAST EQUIPMENT— LOOP-DISCONNECT IMPULSING.

While the paper so far has dealt with the main loop-disconnect impulsing principles, the various effects, particularly pick up, have been discussed with relation to non-ballast equipment. Ballast equipment introduces slightly different conditions, and the various effects will now require to be discussed in relation to these new conditions. From the impulsing aspect, the main concern is the A-A ballast impulsing relay.

The surges which occur during impulsing and pick up have a greater effect on the ballast relay than on the non-ballast, as the former is more sensitive on release.

Consider first the rectified shunt field relay applied to ballast equipment (ref. Fig. **19** (*a*)). With this arrangement it was found that the permissible dial speed under short line conditions fell considerably due to excessive make period. This resulted from surge re-operation of the A-A A relay during the first break of the dial, the effect being accentuated by the gradual decay of the A relay current on the first break under the short line condition (C1 contact not operated), the D and I relays being in circuit.



(a) 'M' REPETITION CONTACT (b) K REPETITION CONTACT

FIG. 19.—BALLAST A-A RELAY-SET—" K " REPETITION CONTACT.

This was overcome by replacing the normal repetition M contact A1 by a K contact (see Fig. **19** (*b*)), the back spring placing a short circuit across the back bridge before relay C operates on the first break. This arrangement gives a partial simulation, immediately on first break, of the conditions on subsequent breaks when contact C1 takes over the short-circuiting function. This A contact short-circuit accelerates the A relay current decay on first break and reduces the oscillation tending to re-energise the relay.

It will be noted from Fig. **19** (*b*) that the shunt field D relay is replaced by an ordinary relay rectified to give the unidirectional operating feature.

7.1 Initial Pick Up.

The rectified D relay associated with ballast equipment ensures an adequate initial pick up limit.

7.2 Subsequent Pick Up.

False impulses on S.P.U. occur more readily with the ballast relay than with non-ballast, so much so, in fact, that even with a rectified D relay, false impulses may occur on inter-A-A relay set junctions of 400 ohms. For this reason the back bridge was modified to improve S.P.U. performance, the modification consisting of an 800 ohm N.I. resistance across the lines, controlled by contact CA1, the CA relay being controlled by the C relay. Fig. **20** shows the arrangement which is known as the " two stage drop back," as the drop back to the holding condition is accomplished in two stages, first the 800 ohm resistance and D and I relay circuits in parallel, and second the D and I relay circuit only.

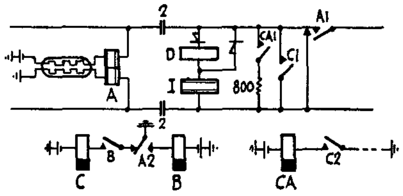


FIG. **20**.—BALLAST AUTO-AUTO RELAY-SET. TWO STAGE DROP BACK SUBSEQUENT PICK UP SCHEME.

When contact C1 releases the current is momentarily transferred to the 800 ohm path of CA1, the current subsequently beginning to rise in the D and I relay circuit. By the time CA1 releases (slow release) to disconnect the 800 ohm resistance, the inductive effects of the D and I relays are mainly overcome and the A relay holding current is maintained. The virtue of the arrangement is the gradual introduction of the D and I relays into the holding circuit which reduces the tendency of the A relay current to fall to zero, and the changes of potential on the line condensers are less violent.

The arrangement increases the S.P.U. limit of inter-A-A relay set junctions to 1000 ohms.

Under practical conditions in the field, mixtures of ballast and non-ballast equipments will be met on tandem connections, and as not all non-ballast equipment incorporates the rectified D relay, the possibility of S.P.U. troubles will arise. As mentioned previously, however, the extent to which S.P.U. troubles may occur depends on the relative A-A relay-set and selector C relay release lags, as well as on the critical values of junction resistance. The effects are consequently somewhat fortuitous, so it cannot be said that false impulses will always occur under such mixture conditions.

7.3 Called Subscriber Answer Pick Up.

As with non-ballast equipment, C.S.A.P.U. reduces the ballast inter-A-A relay-set junctions to 800 ohms.

8. LOOP-DISCONNECT IMPULSING OVER AMPLIFIED LINES.

It is not strictly correct from an impulsing point of view to state amplified line limits in terms of resistance of line unless the limits are qualified by the particular type of conductor to which they refer. It is more correct to specify limits in terms of time constant of line, *i.e.*, $C.R.L.^2$ where C = capacitance and R = resistance, loop mile constants, L being the length of line in miles. Such limits do not require qualification for particular types of cable, although an over-riding resistance limit is necessary.

The time constant of the line determines the steepness of the impulsing wavefronts. Considering the arrival wavefront, increased line time constant degrades the steepness, and this is further degraded by the inductance of the impulse receiving relay.

The main difficulty with loop-disconnect impulsing over amplified lines occurs on break. It has already been explained that one effect of the condenser across the impulsing springs as compared with the non-condenser circuit is that the initial current decay wavefront does not fall as rapidly under otherwise equal conditions. This is due to the initial condenser charging current on break. The same effect occurs, but to a considerably greater degree, when impulsing over amplified lines. On break the sending end is on open circuit, and the line charges to the potential of the battery behind the impulsing relay. This charge current flows through the windings of the impulsing relay and delays its release. Due to the distributed resistive and capacitive components of long amplified lines, the line charging time constant is high, thus the decay wavefront is extremely gradual, resulting in a considerably decreased break period. The actual effect on the impulsing relay depends on the relative values of cable resistance and capacitance, the capacitance tends to reduce and the resistance to increase the break period. On the longer lines the resistance may have more effect than the capacitance. On the shorter lines the capacitance tends to predominate. This is particularly so on 2-wire reactive circuits, but as a general rule the high capacitance of the phantom on 4-wire circuits causes a progressive decrease in break period as the line length increases in spite of the increasing line resistance.

The general type of impulse waveforms over long amplified lines is shown in Fig. **21**, and the decreased relay break period is clearly evident. Due to the slow wavefronts relay performance variation has a considerable effect on the relay output. It is obvious that performance would be considerably improved if the release current value of the impulsing relay was high. One of the main points to be appreciated, however, is that the type of distortion is the same as that resulting from *short* non-reactive lines. Thus, impulsing over *long* amplified lines results in *short* line failure, *i.e.*, inadequate break.

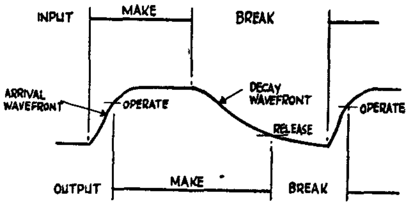


FIG. 21.—LOOP-DISCONNECT IMPULSING OVER 4-WIRE AMPLIFIED LINES. TYPICAL ARRIVAL AND DECAY CURRENT WAVEFORMS.

Conditions would be improved to some extent if the signalling speed was sufficiently slow to avoid mutual interference between the decay and arrival current wavefronts on successive signals, *i.e.*, to enable the decay wavefront to attain steady (zero) state before the next arrival wavefront begins. It is for this reason that impulsing performance over amplified lines is sometimes referred to in terms of permissible dial speeds. A typical permissible dial speed—length of line relationship—is shown in Fig. **22**, and the progressive decrease in dial speed with increasing 4-wire line should be noted. The 2-wire reactive line curve is included in Fig. **22** for comparison, the upward trend of the curve on the longer lines being due to the resistance predominating.

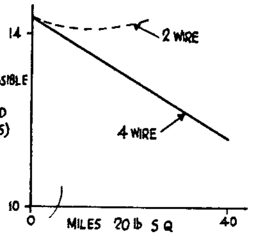


FIG. 22.—PERMISSIBLE DIAL SPEED-LENGTH OF S.Q. CABLE. SINGLE JUNCTION CASE.

Fig. **23** shows a typical relationship between impulse distortion and varying dial speed over a fixed line, and the increase in distortion with dial speed, due to increasing mutual interference between the wavefronts, should be noted. The zero line (leaky) performance curve is included for comparison, and it is seen that the same type of distortion occurs.

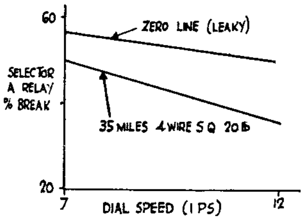


FIG. 23.—IMPULSE DISTORTION—DIAL SPEED SINGLE (AMPLIFIED) JUNCTION INPUT 63% BREAK.

Impulsing over amplified lines in tandem presents a considerably more serious problem, as each tandem link gives the same type of distortion. The overall effect is accumulative, and the permissible dial speed is still further reduced. Conditions are improved on tandem working if a subsequent link to a long amplified line is a long non-amplified line, as the resulting long line distortion (increase of break) from this link would offset the short line distortion of the amplified line. A short non-amplified tandem link is obviously more onerous.

9. BATTERY DIALLING.

This method is used extensively for dialling from manual boards into distant automatic equipment. Fig. **24** shows the fundamental impulsing circuit. Since impulsing takes place over one leg of the junction, the return circuit being earth, it is possible to dial over higher resistance than " loop " dialling will permit, but, due to this leg condition, the system is subject to earth potential difference limitations. The impulsing is by loop-disconnect, and the waveforms are of much the same character as those of loop-disconnect " loop " dialling.

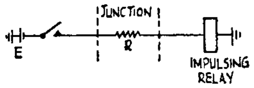


FIG 24.—FUNDAMENTAL BATTERY DIALLING IMPULSING CIRCUIT.

The present battery dialling arrangements give rise to two difficulties when impulsing over amplified lines:—

(*a*) Excessive impulse distortion ;

(*b*) Interference ;

and as manual board to automatic exchange junctions are very often amplified, these difficulties have tended to restrict the application of the system. Excessive impulse distortion also arises on long reactive non-amplified lines.

While excessive impulse distortion over long amplified lines (*i.e.*, decrease of break) is to be expected from any loop-disconnect system, the present battery dialling circuit further degrades the performance by virtue of the design of the impulsing relay. One design of relay is used over all the voltage ranges, while the manual board end arrangements differ in circuit and voltages. There is no doubt that performance could be improved if a number of different relays were used, each designed to function at the specific voltages.

A further difficulty is that the tandem junctions are invariably short (*e.g.*, Main to Satellite) and give rise to the same type of distortion as that when battery dialling over the amplified junction. The distortion is thus cumulative and tandem dialling becomes difficult. Here again tandem working tends to be better over long than over short subsequent links.

Two sources of interference arise when battery dialling over amplified lines:—

(*a*) Interference in the cable itself due to the unbalanced leg impulsing condition.

(*b*) Interference due to the common grid bias circuit on the amplifier bays.

Cause (*a*) gives rise to disturbance on other circuits in the cable, and while this may not be serious on unamplified lines, the phantoms of 4-wire star quad circuits are not balanced against cross-talk, and the disturbance tends to reach appreciable proportions.

The chief source of interference is (*b*). A large current surge in the windings of the hybrid transformer occurs on make of the dial springs, and a considerable voltage is developed across the secondary winding of the input transformer of the amplifier. Surge volts are thus developed across the common grid bias resistor, and are communicated to all the amplifiers on the same bay. This interference can be considerably reduced by large values of common grid bias decoupling capacitance, or, better still, by such design that common grid biassing is avoided. The common decoupling condenser associated with the modern 20A amplifier is 500 μF (as compared with 4 μF in previous types) and the interference is considerably less.

10. DISADVANTAGES OF CONDENSER TYPE TRANSMISSION BRIDGES.

Multi-exchange areas consist of a multitude of exchanges with a variety of equipment, each having different impulsing characteristics, linked by junctions of varying lengths and composition. Ideally, the junctions should be of the most economical type for speech transmission. If impulsing limitations exist, their extent should be known with fair precision, otherwise there is risk of bad service or expensive line plant provision. With condenser type bridges it is impossible to evaluate impulsing with precision, due to the number of variables, and every combination of variables has to be separately determined experimentally, as switching surges have an unpredictable effect on impulsing over any particular tandem set up.

It is evident that from an impulsing aspect there are distinct disadvantages with the use of condenser bridges, and it would be of advantage at this stage to summarise the points as follows:—

(*a*) The respective links are not self-contained from an impulsing aspect, the relay performance being affected by conditions obtaining in the adjacent sections (*i.e.*, surge effects). Thus, impulsing performance cannot be predetermined.

(*b*) The signal shape is degraded by the high inductance and high eddy current effect of the 3000-type impulsing relay.

(*c*) The relay, having large electro-magnetic and mechanical inertia, is relatively slow in action, and mechanical variations within permissible tolerances have a considerable effect on the efficiency of the impulse repetition.

(*d*) First impulse distortion is appreciable.

(*e*) Pick up troubles due to the high impedance line relays.

No further elaboration is necessary to indicate that the condenser type transmission bridge is far from ideal to meet the D.C. impulsing requirements of the increased size and complexity of modern networks.

11. TRANSFORMER TYPE TRANSMISSION BRIDGES.

A relay having the smallest possible inductance, and storing the least possible energy, is desirable for impulsing. Such a relay is necessarily of low impedance, and, whilst for this reason it is unsuitable for condenser bridges, it is eminently suitable for transformer bridges. As the relay need not be high impedance, it can be of the high speed type. Fig. 25 shows the loop-disconnect impulsing transformer bridge with high speed relay.

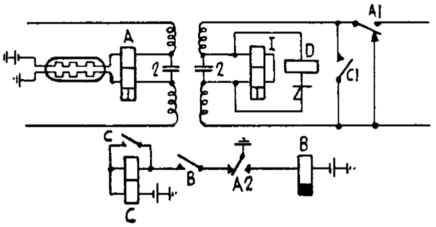


FIG. 25 —TRANSFORMER TYPE TRANSMISSION BRIDGE.

The advantages of this bridge can be summarised as follows:—

(1) Reduced impulse distortion, allowing more links in tandem.

(2) Each link self-contained from an impulsing aspect.

(3) Negligible first impulse distortion.

(4) Reduced pick up difficulties.

(5) Predictable impulsing performance.

Considering these points in further detail:—

11.1 Impulse Distortion.

The signal shape is improved by the use of a relay in which eddy currents and impedance are considerably reduced. In the high speed relay, the reduction of eddy currents contributes perhaps more to this improvement than reduction in impedance. The transformer operates to the detriment of the signal shape, but to a very small degree. This also means that there is negligible difference between the first and subsequent impulses, since the only change in the impulsing circuit during a train of impulses is in the transformer impedance. The high speed properties (1 – 2 mS. operate) of the relay allow full advantage to be taken of the improved signal shape, and reduce the effect of relay adjustment on impulsing performance. In particular, the construction and high speed action of the relay eliminate troubles due to contact clearance on which the performance of 3000-type impulsing relays is so critically dependent.

11.2 Switching Surges.

Comparing the condenser and transformer bridges, both types are liable to switching surges from the same causes. The difference resides in the magnitude of the surges and their effect. The surges in a transformer bridge are smaller in magnitude and duration by reason of the different reactances in circuit and quicker operation of the repeating relays. The effect of the surges, however, is very different in the two bridges. The nature of the coupling between the input and output of the transformer bridge eliminates the transmission of longitudinal surges for all practical purposes, so that the impulse shape on one link is not modified by the switching condition in the others. However, it is still possible for transverse surges to produce interference of sufficient magnitude to affect the impulsing performance of any one path. These transverse surges are suppressed by the operation of contact C1 at each tandem point, and the effect is thus limited to the first break, and with a transformer bridge the effect is small. Fig. **26** shows the condition when C1 is operated. The secondary winding of the transformer is a local circuit devoid of earth or battery connections and connected at only one point to any other conductor. Currents induced in the secondary due to changes in the primary can circulate only in this local circuit. Moreover, the conditions appertaining to the secondary are constant and are not affected by varying conditions obtaining further along the line, and thus any effect the secondary load may have on the primary is constant.

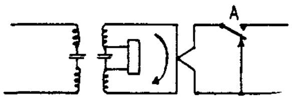


FIG. **26**.—TRANSFORMER BRIDGE—CONDITION WHEN C1 CONTACT OPERATED.

Fig. **27** shows typical waveforms obtained with condenser and transformer bridges under equal conditions of line, and the almost complete absence of bridge inter-action in the transformer bridge should be noted.

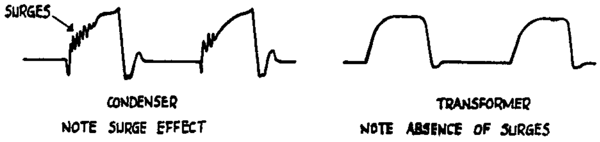


FIG. **27**.—COMPARATIVE IMPULSE WAVEFORMS CONDENSER AND TRANSFORMER BRIDGES.

11.3 First Impulse Distortion.

With the transformer bridge, arrangements are made for a short-circuit across the back bridge to be applied immediately the impulsing relay makes on its back contact (contact A1, Fig. **25**) and inter-action is effectively prevented from this time. As this short-circuit is applied about 1 mS. after the loop is opened, the effect is negligible.

While the initial seizure loop may include a preceding D and I relay circuit, the C1 short-circuit being applied for subsequent impulses, the effect is still negligible, as, due to the rapid release time of the high speed relay, any variation is less as compared with the 3000-type relay which has a longer release time.

11.4 Pick Up.

Initial pick up trouble is non-existent due to the low impedance line relays and the quick action of the impulsing relay. Further, it is proposed that the resistance of the D and I relay circuit be reduced by the relays being connected in parallel. The direction of the rectifier being such that the resistance of a preceding back bridge is a minimum when the connection is being set up.

Subsequent pick up trouble is negligible as, due to the small impedance of the D and I relay circuit, the resulting drop of current on drop back to holding is of less duration. The response of the high speed relay is instantaneous, so that it is not released for sufficient time to cause false operation of selectors.

Called subscriber answer pick up trouble is reduced as, due to the nature of the high speed relay design, the effect of the flux reversal is not so onerous.

11.5 Pre-determination of Impulsing Performance.

In any impulsing system the extreme routing conditions are determined by excessive loss of make due to long line distortion or excessive loss of break due to short line. With condenser bridges, there is no convenient way of determining whether or not any particular tandem route would give satisfactory performance, the only way being extended trials. With transformer bridges the links are self-contained from an impulsing aspect, as surges do not pass through the bridges, each link distortion is additive and thus the performance of links in tandem can be predicted with fair accuracy by simple calculation based on generalised data for single link working.

There are, however, two inherent difficulties in the application of the transformer bridge:—

(*a*) On very short amplified lines, the condenser in the line terminations, together with the high speed response of the relay, tends to give rise to impulse splitting. On slightly longer amplified lines split impulsing does not arise, but the make period tends to increase due to the effect of the line terminations on the signal shape. These difficulties are probably more theoretical than practical, as the short amplified lines which give rise to them would not be a usual condition in the field.

(*b*) High speed relays are very responsive to line surges, and subsequent pick up troubles would arise should the transformer bridge be preceded by one of the condenser type, particularly when the " two stage drop back " feature is not incorporated in the condenser equipment. This is a real practical difficulty, as it tends to limit the extent of inter-working with existing equipment in the field.

There is no doubt, however, that the impulsing principles embodied in the transformer bridge are a considerable improvement over those of the present condenser type bridges.

12. IMPULSE CORRECTION.

Impulse correction as opposed to impulse regeneration may be defined as a process in which the relays concerned with the impulse repetition are mainly influenced directly by the received impulses, but have also a subsidiary control which tends them to correct the ratio. No impulse storage is involved. In general, any method other than complete train regeneration can only correct the ratio and cannot alter speed. It is, however, impossible for the speed to have altered during transmission, so that under normal circumstances it may be argued that there is no need for it to be corrected.

The impulse target diagram, Fig. **28**, shows the fundamentals of impulse correction, the ideal output ratio over the complete speed range being 2B:1M (line OG). Impulse correction in which a certain fixed speed is assumed and a new break (or make) period of fixed duration is generated for each impulse, has the obvious objection that different speeds of reception will produce output impulses of widely varying ratio. Suppose the input at all speeds is 2:1 ratio, and that the transmission medium and repetition are such that excess break distortion results; this can be represented by line AB, or if excess make results, by line DE. If the output break is of fixed duration (say 66 mS) the output ratio over the speed range will be represented by line LM, and the divergence between LM and the ideal ratio output OG is clearly seen. Similarly, a fixed make output (say 33 mS) would give an output represented by line HK, which is again widely different from OG. Reasonable performance with fixed break (or make) correctors can only be obtained with very closely controlled impulse speeds.

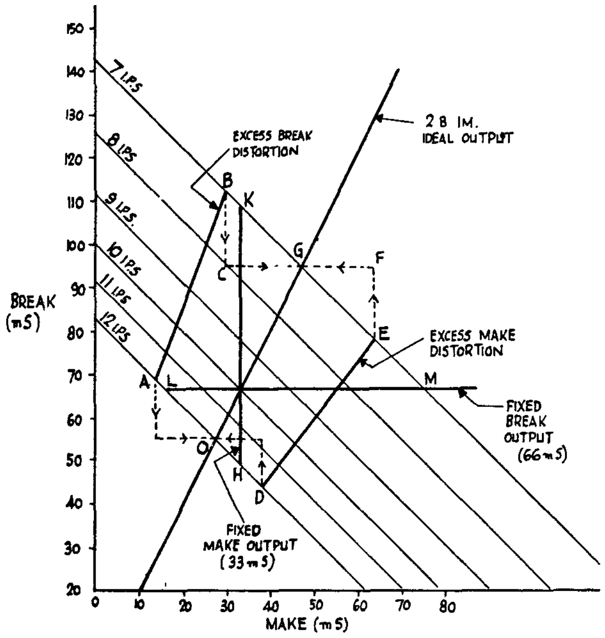


FIG. 28.—TARGET DIAGRAM—IMPULSE CORRECTION.

A further type of impulsing improvement has been used which is more fundamentally regeneration than correction. This is based on the idea of ensuring that at least a minimum break and a minimum make are transmitted. Thus, the original impulse is transmitted unless it has deteriorated so far that its break or make has become shorter than the maximum permitted, when the regenerated minimum becomes effective. The objection to this method is that to prevent excessive deterioration of a slow train, the minimums have to be set fairly large, but, on the other hand, if the speed of a received train is above that produced by the permitted minimums, then complete failure occurs.

It is clearly undesirable to introduce special arrangements for close speed control, and yet it is equally undesirable to permit widely varying output ratios over the speed range. Thus the fundamental problem of impulse correction is to obtain a 2B:1M ratio over the complete speed range of 7—12 i.p.s. To accomplish this, it is probably possible to regenerate each individual impulse immediately after reception. This would involve measuring by some means the duration of each impulse (break plus make) and producing a new impulse of the same total duration but having a correct ratio. The difficulty in designing means to accomplish regeneration of each impulse is that after measuring the duration of one impulse it is either necessary to relieve the measuring device of the information it has obtained, in order that it can measure the next impulse, or to duplicate the measuring devices. Another difficulty is that in an impulse train the number of breaks is one more than the number of makes, so that a manufactured arbitrary make has to be arranged for either preceding the first, or following the last break. This manufactured make must assume a fixed input speed, and thus first (or last) impulse distortion arises at other speeds.

Fundamentally, however, it is obvious that some measurement of the received impulse is necessary before steps can be taken to apply proper correction. If the character of the complete impulse (break plus make) is determined before action is taken, then it is too late to correct that impulse unless a phase displacement of approximately a complete impulse is introduced between reception and transmission.

The ideal method appears to be one in which each component (make and break) is measured independently, and correction applied immediately on the completion of each measurement. It is not, however, at all obvious at first sight how a suitable correction can be made dependent on the measurement of one component (make or break) and a further difficulty appears to arise if, after measurement, the component has to be shortened instead of lengthened.

A more practical method is to measure one component, say the break, and then determine the correction to be applied to give a 2:1 ratio output at all speeds. Each component (break) could be corrected in two stages, first by an adjustment dependent on the preceding make condition, and secondly on an adjustment dependent on itself. With this method, the break at point B (Fig. **28**) would be decreased by BC, and the make thus increased by CG (CG = BC) thus moving B to G to give a 2:1 ratio. Similarly, the break at E would be increased by EF, and the make reduced by FG (FG = EF) to move E to G. Similarly at other speeds.

With the first break of a train, there is no preceding make component from which to determine the first stage of correction. As mentioned previously, this difficulty may be overcome to a certain extent by assuming the first break to be preceded by a perfect make at 10 i.p.s. (33 mS) and circuit arrangements made to manufacture such a condition. First impulse distortion would result at all dial speeds other than 10 i.p.s.

Correction devices to give a fixed make or break output by fixed time base are relatively simple, but those to give a 2:1 ratio output are apt to be complex. The devices are dependent for their accuracy upon manufacturing tolerances of the various components, upon the adjustments of the relays involved, and upon the overall effect on all components of variations in battery voltages. It has been suggested that it may perhaps be possible to fit impulse regenerators at the outset of a call in a tandem train, and, due to the controlled speed, provide a simple fixed make or break output correction device at subsequent points. This introduces a certain difficulty, as any junction is always liable to be used as a first as well as an intermediate link.

12.1 Impulse Correction Schemes.

A considerable number of impulse correction devices are in use, particularly in America and Germany, and the scope of this paper limits description to two typical examples.

Fig. **29** shows a fixed break output corrector as used in America. A1 on break operates D, and D1 starts the output break. D3 operates E, and E1 disconnects D from the A1 circuit, but D2 operated allows condenser C to charge through D, the charging current being in the holding direction for relay D. As condenser charge increases, the flux in D diminishes, and thus the termination of the output break is delayed by the charging of the condenser. When D releases, condenser C discharges to D2. Thus D and C form a fixed time base. The weakness of the scheme is that the condenser time base circuit is ineffective when the received break exceeds the charge time constant of the condenser circuit.

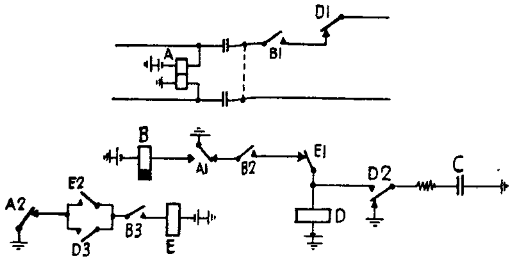


Fig. **29**.—Impulse Correction—Fixed Break Output (American).

Fig. **30** shows a minimum break minimum make output corrector as used in Germany. On make, A1 operates H, and H1 commences output make. H4 disconnects E (slow release) and operates F. H holds to A1 via H2 until the end of the received make, when A1 releases, and if the input make is too short, E will not have released by the time it has ended, and H will now be held via E1. The output make is thus at least as long as the release lag of E. After H has released during the received break, F releases and E is energised. During the release time of F relay, H cannot operate, since F1 breaks the circuit. An output break is therefore enforced whose minimum duration is equal to the release lag of F.

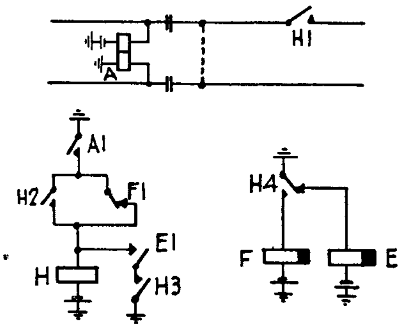


Fig. **30**.—Impulse Correction—Minimum Break Minimum Make Output (German).

This scheme would give a very limited performance. At slow speeds the impulse ratio may not be influenced in any way. At high speeds, the received makes and breaks may be shorter than the release times of relays E and F, and output impulses would become more and more deformed. The relative times of E and F must be so chosen that their sum total is equal to the shortest total impulse duration, but it is difficult to control relay times to any close limits.

13. IMPULSE REGENERATION.

Impulse correction devices correct for ratio only, but impulse regenerators have the virtue of independent output, and can correct for both speed and ratio. It is necessary for the regenerator to store the information because clearly it cannot otherwise transmit impulses more slowly than it receives them. Fig. **31** illustrates this, and assuming no storage, input speed 12 i.p.s., and output 9 i.p.s., only two impulses are transmitted for three received. Slow input and fast output may result in the transmission catching up with reception, and to avoid this, it is usually arranged for a train to be completely stored before the transmission of that train commences.

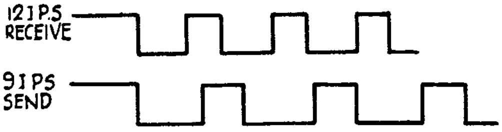


Fig. **31**.—Impulse Regeneration—Fast Input Slow Output.

The regenerative device may be mechanical or electrical. The Mechanical Impulse Regenerator is already in use by the Department, and the Electrical Impulse Regenerator is in process of development.

13.1 Mechanical Impulse Regenerator.

This has been adequately described elsewhere.* Briefly, the item consists of two elements (1) receiving and marking, and (2) transmitting, which can function out of phase and independent of each other. The input is received and the beginning of each train marked by displacing a storage pin. To start the sending of each digit, a transmit magnet is operated by associated relays to reset the displaced pin on which the transmitting element last stopped. This allows a large gear wheel to rotate and generate impulses, one impulse for each normal storage pin traversed, until the next displaced pin is reached. The output speed is controlled by a governor.

13.2 Electrical Impulse Regenerator.

This device has been proposed by Messrs. Standard Telephones and Cables, Ltd. The storage is performed by a multi-element condenser, reception and transmission being carried out by two standard uniselectors and an impulse generator. The principle is shown in Fig. **32** where R is the receive and S the send uniselector, VB being the impulse generator.

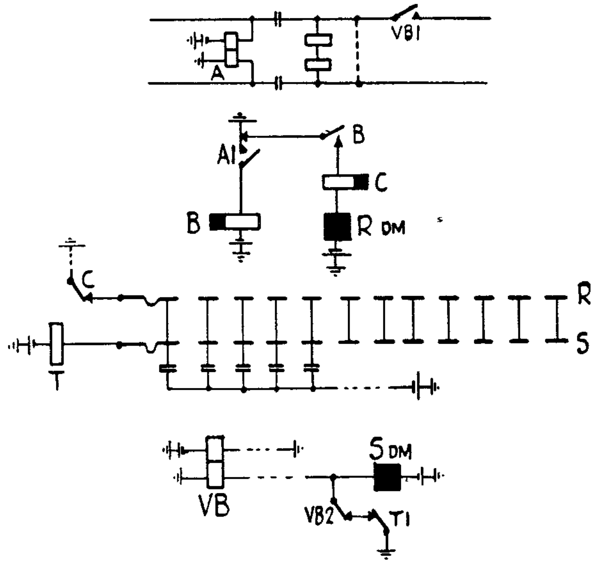


Fig. 32.—S.T.C. Electrical Impulse Regenerator.

The R uniselector is stepped by each received impulse. One level of R has one side of a condenser connected to each contact, the other side being connected to battery. On completion of a received train, C contact releases in the usual manner, and the contact reached by the uniselector is marked by an earth which, in addition, charges the condenser connected to that contact. The receive uniselector may continue to step under the control of a further incoming train, the marking of the bank for the first train being maintained by the charged condenser. A second uniselector performing the function of a send switch, and having one level suitably cross-connected to the receive uniselector, is then caused to step to the marked contact by a vibrator (VB) which is simultaneously sending standard impulses to line. The output train is terminated by the operation of relay T when a marked contact is reached, this relay being sensitive enough to operate to the condenser discharge. A contact on T disconnects the vibrator to terminate the output train and the stepping of the send uniselector. Arrangements are made for T to be released after a time period which can be of any duration (*i.e.*, the controlled inter-train pause) and the sending then re-commences.

The one uniselector can be made to store any number of digits provided the sum of the digits does not exceed the number of contacts on the bank. In this respect the electrical regenerator can be compared with the mechanical item which stores on a ring of pins.

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. The main objection to regeneration lies in the fundamental delays associated with the storage feature, these delays increasing progressively as the number of tandem regenerators increase. Against this, however, the advantages associated with storage must be compared. These are:—

(*a*) Good output speed and ratio.

(*b*) The output inter-train pause can be controlled to any value, irrespective of the number of impulses in a train. This is an important feature, as modern technique requires more and more functions to be completed during inter-train pauses, and the point is being reached where the normal dial pauses are becoming inadequate. It is probable that this advantage alone, apart from (*a*) above, may in the future justify the application of a regenerative, or other storage device, at the outset of a call.

14. "DISTORTIONLESS" IMPULSE REPETITION.

Impulse correction and impulse regeneration are methods for converting poor received impulses into impulses of sufficient quality to actuate automatic switches. It may be argued that such devices are justified, as they permit the use of a simple, but fundamentally poor, impulsing technique such as loop-disconnect and the employment of a relatively simple impulse receiving relay. It has already been shown, however, that corrective and regenerative devices have distinct limitations and difficulties. The obvious alternative is that the impulsing technique should be such that impulses are repeated directly, with minimum distortion, without the necessity for

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* P.O.E.E.J., Vol. 30, Part 4.

correction or regeneration. The ideal is that the repetition should be distortionless, but, due to various permissible tolerances, this would not be possible under all conditions, and the term " distortionless repetition " will be used for the purpose of this paper, on the understanding that a certain amount of distortion, but to close limits, is inferred. Thus three alternatives present themselves for the purpose of increasing the impulsing range above the limits of ordinary loop-disconnect impulsing: (1) correction, (2) regeneration, and (3) distortionless repetition, and the possibilities of the third will be discussed later with particular reference to D.C. impulsing over long lines.

15. LONG DISTANCE D.C. IMPULSING PROBLEM.

Long audio circuits are invariably 4-wire amplified, and the phantom utilised as the signalling path. D.C. impulsing over such circuits calls for a technique different from loop-disconnect impulsing.

15.1 Non-Symmetrical Waveforms.

Loop-disconnect impulsing results in non-symmetrical received signals, and on long reactive lines the decay wavefront is considerably more gradual than the arrival, due to the line charging through the coils of the impulsing relay during the open circuit period (break). A condition for correct signalling is that the decay wavefront should reach steady (zero) state before the next arrival wavefront begins, and to meet this condition the next pulse would have to be delayed and impulsing slowed up. At the maximum dial speeds permitted by the usual tolerances, mutual interference between the wavefronts occurs on relatively short lines to give excessive impulse distortion.

The impulsing relay functioning between operate and release introduces impulse distortion due to the electrical and mechanical difference between the operate and release conditions. This is evident from Fig. **21**, where the foot of the decay wavefront is extremely gradual, and a slight change in relay release current would result in an appreciable change in release time and impulse distortion. A slight change in the operate current would not have such an appreciable effect, as the arrival wavefront is relatively steeper around the usual operate region.

Also, varying lines give varying signal amplitudes, and as the impulsing relay has fixed operate and release current values, varying impulse distortion would result.

It is obvious that loop-disconnect impulsing is completely unsuitable for long distance D.C. impulsing, and it is equally obvious that advantage would be gained if the decay wavefront was made more steep, *i.e.*, symmetrical wavefronts.

15.2 Symmetrical Waveforms.

There are a number of methods for ensuring symmetrical signals. Considering Fig. **33**, signals are generated by changing the sending battery from 0 to E volts. On break of the contact, the arrival curve is much the same shape as that with loop-disconnect impulsing. On make of the contact, the line is short-circuited at the sending end. Thus the sending end impedance is the same under both the make and break conditions, and the arrival and decay wavefronts are consequently symmetrical, as shown in Fig. **34**. With this arrangement, current is sent to line during the break of the contact, and ceases during the make, the reverse of loop-disconnect. The make signal is generated by a loop, and the break by battery at the sending end, and an appropriate name for this impulsing method is " loop-battery," as distinct from " loop-disconnect."

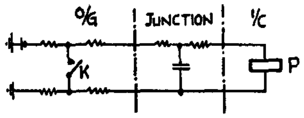


FIG. **33**.—LOOP-BATTERY IMPULSING CIRCUIT.

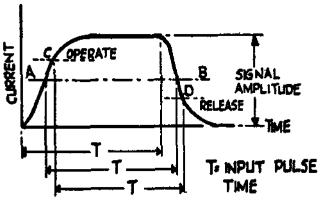


FIG. **34**.—SYMMETRICAL SIGNALS.

From Fig. **34** it is seen that, with symmetrical wavefronts, the input pulse time T is reproduced at the midway line AB, so that if the relay operated and released at the same current value equal to half the signal amplitude, or if the operate and release points fell equally about the midway line, say at C and D, distortionless reproduction of the input would be obtained.

An impulsing relay has fixed operate and release current values, and while these may be arranged to fall equally about the midway line at one particular signal amplitude, this would not be possible at other signal amplitudes, and distortion would result. This is shown in Fig. **35**, which shows current-time curves for two signal amplitudes X and Y. Assuming the relay operate and release current values are set at the midway line AB of the Y amplitude, operating at C and releasing at D, the relay will reproduce the input pulse time T. Should this same relay be applied to the X amplitude, it will still operate and release at

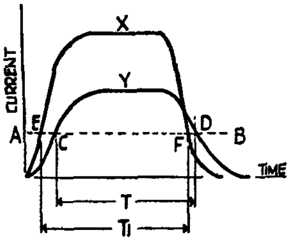


FIG. **35**.—EFFECT OF VARYING SIGNAL AMPLITUDE ON IMPULSE DISTORTION.

the same current values, operating at E and releasing at F to give an output pulse time T1, which is greater than T. The input pulse would be distorted by T1 – T by the repetition, and, similarly, at other signal amplitudes on other lines. The same reasoning applies if the relay operate and release current values fall equally about the midway line AB. Thus, to reproduce the input pulse time at all signal amplitudes, the relay would require to be specially adjusted to each signal amplitude, meaning a separate adjustment for each line length which is clearly undesirable.

This separate relay adjustment problem can be overcome by shifting the midway line AB of Figs. **34** and **35** down to the zero current axis by means of double current or double current effect working.

In long distance D.C. impulsing, the short make period at high impulse speeds and high break ratio is an onerous condition, as on lines of high time constant, even with symmetrical signals, there may not be sufficient time for the decay wavefront to reach zero steady state before the next signal begins, and mutual interference between the wavefronts results. Relatively ample time is available during the break period, and there is no doubt that considering the propagation of the signals over the medium, a 1M:1B ratio at the usual dial speeds would be of advantage. This would involve conversion from normal to 1:1 ratio at the sending end, and reconversion from 1:1 to normal at the receiving end to actuate the automatic equipment. Such conversions could be accomplished by regenerative devices, but would add to the complexity of long distance D.C. working. It should be possible to obtain substantially steady state impulsing over all the audio media likely to be met in this country, and, providing the initial automatic switches are satisfactorily actuated by the dial, the principle of minimum distortion on subsequent impulse repetitions might permit satisfactory operation of subsequent automatic switches up to the maximum number of links in tandem likely to be required by the future dialling requirements in this country. This is dependent on the initial dial speed and ratio, and while the conditions may be met with operator dialling, possible wide variations from subscribers' dials might introduce difficulties should subscriber-to-subscriber dialling without operator assistance ever be contemplated on the Trunk and Toll network. The advantages of closely controlled speed and ratio, together with adequate inter-train pause, can be obtained by means of a regenerative device fitted at the originating exchange for all long distance traffic, and the possibilities of this principle will require careful consideration.

15.3 Double Current Working.

This may be defined as the transmission of signals by means of reversals of a single electric phenomena. The advantage is the reduction of received signal distortion obtainable by causing the receiving relay to operate and release at or about the half amplitude points on the received signal waveform with time. This effect is achieved by making these points of zero amplitude and using a balanced or neutral receiving relay of the polarised type. The performance of such a system is independent of signal level. Figs. **36** and **37** show the well-known Double Current and Double Commutation methods of obtaining this effect, and Fig. **38** shows typical current-time waveforms. The midway line AB (Fig. **35**) has now become the zero datum line, with the difference that this datum applies to all signal amplitudes, whereas in the single current circuit, the midway line AB referred to one amplitude only. The input pulse time T is reproduced between points A and B on the zero datum, and should the relay operate values (in each direction) be set equally about the zero datum, *i.e.*, at points C, D, and E, F, time T is also reproduced between these points. This applies to all signal levels, and consequently the fixed current values of the reception relay do not result in varying distortion with varying signal amplitude. The above reasoning neglects the transit time of the polarised relay. Another advantage of double current is the inherent sensitivity of the polarised relay ; a small ampere-turn value will cause change-over.

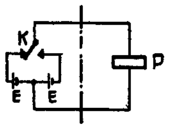


FIG. **36**.—DOUBLE CURRENT.

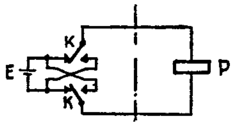


FIG. **37**.—DOUBLE COMMUTATION.

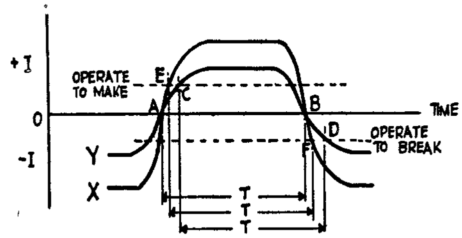
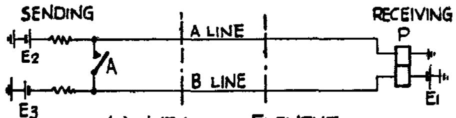


FIG. **38**.—DOUBLE CURRENT WORKING CURRENT-TIME WAVEFORMS.

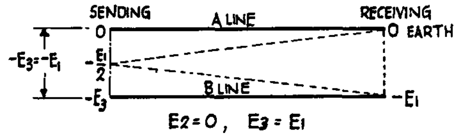
There is no doubt that double current working or double current effect at the reception apparatus is vastly superior to loop-disconnect impulsing, and forms an obvious basis for the solution of the long distance D.C. impulsing problem.

15.4 Single and Double Counter E.M.F. impulsing Methods.

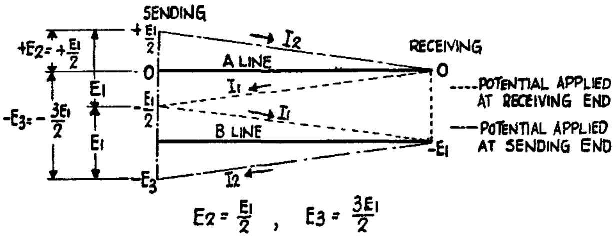
An interesting new development to transmit double current effect over the medium is Double Counter E.M.F. This method permits the polarised relay to function in direct double current manner, and at the same time permits the retention of the supervisory signalling battery behind the relay. Fig. **39** (*a*) shows the arrangement, E_1 being the supervisory battery.



(a) IMPULSING ELEMENT



(b) POTENTIAL GRADIENTS - SINGLE C.E.M.F.



(c) POTENTIAL GRADIENTS - DOUBLE C.E.M.F.

FIG. 39.—SINGLE AND DOUBLE COUNTER E.M.F. IMPULSING.

First consider the Single Counter E.M.F. (single current working) condition in which $E_2 = 0$ and $E_3 = E_1$. Fig. **39** (*b*) shows the potential gradients with reference to earth zero potential. When A1 operates and the line current attains its steady state, the potential of the A line falls uniformly from zero at the receiving end to $-\frac{E_1}{2}$ at the sending end. The potential of the B line rises uniformly from $-E_1$ to $-\frac{E_1}{2}$ at the sending end. Hence, at the sending end, both lines are at the same potential $-\frac{E_1}{2}$ with respect to earth.

When A1 opens, the potential of the A line at the sending end rises from $-\frac{E_1}{2}$ to 0, and E_3 is opposed by the charge $-\frac{E_1}{2}$ in the B line. This E_3 is counter to E_1, and as $E_3 = E_1$, the current decay occurs in a circuit of the same electrical conditions as the arrival and symmetrical single current signals are produced.

Now consider the Double Counter E.M.F. arrangement. Here $E_2 = \frac{E_1}{2}$ and $E_3 = \frac{3E_1}{2}$, Fig. **39** (*c*) shows the potential gradients. When A1 operates, the potential of the A line falls from 0 to $-\frac{E_1}{2}$, and that of the B line rises from $-E_1$ to $-\frac{E_1}{2}$ and current I_1 flows, both sending end wires being at the potential $-\frac{E_1}{2}$.

When A1 opens, E_2 now drives a current into the upper loop via the earth, being aided by the charge $-\frac{E_1}{2}$ on the A line. E_3 will perform a like function for the B line, but is opposed by the corresponding charge on the B line with respect to earth. Thus, current I_2 equal and opposite to I_1, will flow, and the relay functions in true double current manner.

In automatic telephony, the retention of the supervisory battery behind the impulsing relay is desirable to facilitate the passing back of supervisory conditions without circuit complication. This, combined with the true double current effect, makes the Double Counter E.M.F. scheme attractive.

15.5 Single Current Transmission with Double Current Effect.

Single current working may be termed the transmission of signals by means of the presence or absence of single electric phenomena. It has already been shown that symmetrical wavefronts can be obtained from single current transmission, but the whole advantage gained by this symmetry would be lost in the imperfect response of the receiving relay functioning in single current manner.

It is clear that if simple and robust means could be provided whereby a single current transmission could be converted into a true double current effect at the reception end, the distortion would be reduced. Since it is much easier to transmit single current effects, and as many of the present systems are of this form, the merits of such a conversion must be considered as compared with double current transmission. The advantage of the double current method only becomes apparent when the amplitude of the received signal wavefronts departs radically from the rectilinear shape. Assuming that the received signal wavefronts attain substantially steady state from pulse to pulse and are symmetrical, there is no reason why single current transmission with true double current effect at the reception apparatus, should not give equal performance to that of double current transmission.

15.6 Methods of Obtaining Double Current Effect.

There are a number of methods of obtaining double current effect from single current sending, but not all give a true effect at all signal amplitudes. Methods of employing polarised relays with fixed electrical or mechanical bias to give a double current effect are well known, but as they do not give true double current effect at all signal amplitudes, they will not be discussed further.

15.6.1 *L.D.D.C. (Differentiated Current) System.*

This system is completely developed, and has been adequately described elsewhere.* In brief, symmetrical single current signals are transmitted by the loop-battery method, and the arrival and decay current wavefronts are differentiated by means of a transformer. The resultant steep fronted received

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* I.P.O.E.E. Printed Paper No. 178.

voltage waves across the secondary provide double voltage signals which mark accurately the beginning and end of the received current signals. The secondary voltage signals are applied to the grid of a valve, causing the anode relay to operate in a double current manner.

The secondary voltage signals are of double form about a zero datum, and the anode currents are of double form about a nominal setting. Thus, providing the arrival and decay wavefronts are symmetrical, true double current effect will result.

This is a transient system, as only the transient portion of the received signal is used to effect operation or release, permanency being given to these functions by local locking circuits on the anode relay.

This system gives good impulsing performance, but suffers from certain disadvantages, as follows:—

(*a*) Any interference is differentiated on the transformer, and consequently the system is more prone to false operation due to interference as compared with permanent current systems, as both magnitude and frequency of interference must be considered. In permanent current systems, the magnitude only of the interference is the main consideration.

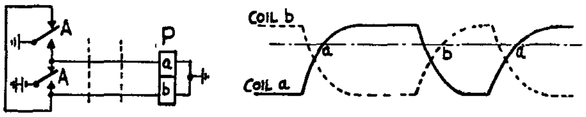
(*b*) Considering a 4-wire circuit terminated 2-wire at the automatic equipment, *i.e.*, the phantom not extended to the signalling equipment, which is the more usual and more flexible condition, the system does not permit the circuit to be directly terminated by the impulsing element, as this is not permitted to signal except for impulsing. The line is required to be terminated on separate signalling relays and then switched to the impulsing element. This results in a relatively long seizure time and difficulties would arise if the L.D.D.C. link was required to be seized from a selector level during normal dial inter-train pause periods. In the L.D.D.C. (differentiated) system, the inclusion of an outgoing regenerator overcomes this and other difficulties, but, as previously discussed, this introduces undesirable delays.

Obvious advantage would be gained if the signalling and impulsing elements were one, and the phantom circuit not required to be extended to the automatic equipment. These two points should be fundamental requirements of long distance D.C. working, and it is hoped to incorporate them in new schemes.

It should be mentioned, however, that under certain conditions, considerable advantage, apart from controlled inter-train pause, can be obtained by preceding an L.D.D.C. link by a regenerator. Short make periods and high time constant of line give rise to mutual interference between the impulse wavefronts and excessive distortion. Distorted input (increase of break) due to a preceding link worsens this condition and should be avoided. A distorted input giving decreased break would be of advantage from the mutual interference aspect, but the direction of distortion of preceding links cannot be always controlled. The difficulty can be overcome by distortionless impulsing incoming to L.D.D.C. links, and the possibilities of this are being investigated.

15.6.2 *Double Flux Commutation.*

The circuit of this arrangement is shown in Fig. **40** (*a*), the impulses being received on a two-coil polarised relay, one coil being supplied with the impulse proper, and the other coil with an inverted signal which is derived from the signal proper at the receiving end. Thus, the disconnect of current is eliminated and symmetrical signals obtained. Fig. **40** (*b*) shows the current conditions for each coil of the polarised relay, and it is seen that each armature operation results from the energisation, alternately, of similar coils, and that current conditions for each operation are identical. Points ' *a* ' and ' *b* ' indicate the operate points for each coil.



(a) IMPULSING CIRCUIT (b) CURRENT CONDITIONS IN COILS

FIG. **40**.—DOUBLE FLUX COMMUTATION.

15.6.3 *Single Counter E.M.F. (Valve Scheme).*

Fig. **41** shows the circuit arrangement for this proposal, single current symmetrical signals being transmitted. The received current signal *i* passes through the terminating resistance *r*. Condenser C charges to a voltage equal to *ir* less the forward voltage drop on MR. On cessation of the signal, C will discharge slowly via R, since the discharge path via *r* and MR is blocked by the back resistance of MR. Hence, the voltage on R is a bias of a value nominally equal to the maximum value of the input signal, and opposing the latter with respect to the grid circuit of the valve. As the tap on R is moved downward from X, a bias is added to the input so that the zero grid current can be altered at will. At the nominal half setting of the tap on R, the input to the valve consists of equal positive and negative excursions of the signal waveform, *i.e.*, double current signals. The total time constant of CR must exceed the longest signal cessation period. These double current signals cause the polarised relay to function in true double current manner at all signal amplitudes.

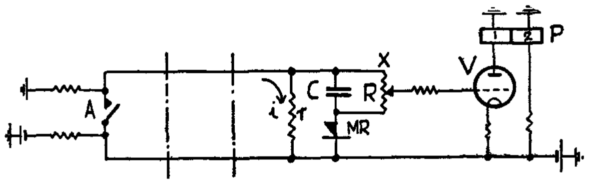


FIG. **41**.—SINGLE COUNTER E.M.F. (VALVE SCHEME).

15.6.4 *Single Commutation D.C. Impulsing.*

Fig. **42** shows this scheme in elemental form. The scheme employs a single contact and a single battery at the sending end and a double coil polarised impulsing relay AP, earthed at the centre point, at the receiving end. Differentially connected relays DP (polarised) and IS are connected in the line wires at the sending end for the purpose of receiving the backward supervisory signals. Thus relays DP and IS with windings so connected, do not respond to loop current, but respond only to earth current. Relay A operates on seizure and A1 operated causes earth current to flow via coil 1 relay AP, A line, coil 1 relay IS, coil 1 relay DP to battery. The B line is short-circuited to earth at each end. Relay IS operates on coil 1 on seizure, relay DP does not operate as the flux is in the same direction as the bias coil flux.

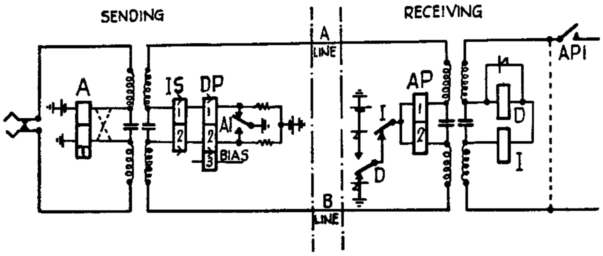


Fig. 42.—Single Commutation D.C. Impulsing.

Operation of contact A1 on impulsing results in relay AP being energised on alternate coils to function in a true double current manner, operating on coil 2 to break and on coil 1 to make pulses. During impulsing there are equal and opposite current changes in each wire of the line and there is no change in the value of the steady earth current. Thus relay AP may be regarded as a " loop " responsive relay responding to reversals of " loop " current.

Relays IS and DP are fluxed during impulsing, but as they are differentially connected there are no flux changes due to the impulsing current reversals. They are thus non-inductive and do not respond to the " loop " current forward impulsing signals. The flux in the line coils of relay DP during impulsing is in the same direction as the bias coil flux and the relay does not operate. Relay IS is operated.

At the receiving end the answer signal is received by relay D and at D1 battery replaces earth at the centre point of relay AP and thus causes a reversal of earth current to operate relay DP on coil 2. The energisation of the bias coil on relay DP predisposes the operation of DP on earth current reversal. The earth current circuit is completed to the A1 contact. Contacts on DP (or relief relay) relay the answer signal. Relay AP is held operated to make by virtue of coil 2 being energised in the corresponding direction.

A loop condition applied behind relay AP will cause the earth current to cease and loop current to flow. Relay IS releases, DP will not respond to the cessation of earth current and relay AP will be maintained operated to make by virtue of coils 1 and 2 being energised in series in the corresponding direction. This additional backward signal could be utilised for Busy Flash.

Thus the differentially connected relays at the sending end respond only to earth current signals transmitted from the receiving end for the backward signals, but do not respond to the " loop " current forward signals. The receiving end relay responds to " loop " current forward signals, but not to the earth current backward signals. Thus independent "loop" and earth current signalling is possible. This arrangement constitutes an extremely simple impulsing and signalling element.

It will be noted that the single sending end contact in the Single Commutation system overcomes the difficulty of synchronising the two sending end contacts associated with the Double Commutation and Double Flux Commutation techniques.

16. FUTURE D.C. WORKING.

With the foregoing discussions on the various impulsing principles in mind, it would be profitable at this stage to formulate proposals, from the D.C. impulsing aspect, to meet the future requirements of Trunk and Toll traffic being completed with the assistance of one operator (outgoing) only.

The requirements of an ideal D.C. impulsing scheme may now be summarised as follows:—

(1) " Zero " impulse distortion, and to realise this:—
  (*a*) Symmetrical current waveforms.
  (*b*) Impulse receiving relay to be polarised or equivalent, to enable full advantage of (*a*) to be obtained.
  (*c*) Polarised relay to be of the balanced armature type.

(2) Each link to be self-contained from an impulsing aspect and not interfere with other links in the same train.

(3) Should not interfere with adjacent cable circuits.

(4) Seizure to be accomplished within the normal dial inter-train pause periods.

Requirements (*a*)—(*c*) and (2)—(4) can be readily obtained ; (2) by the use of transformer type bridges in both the outgoing and incoming L.D.D.C. relay sets ; (3) by balanced " loop " impulsing, and (4) is helped by a scheme not requiring separate signalling and impulsing elements.

The main requirement is (1), as attainment of this might permit tandem dialling to the extent dictated by future operating requirements without the necessity for impulse regeneration on tandem links. Symmetrical signals, together with a balanced polarised relay functioning in a true double current manner, meet the requirement to a considerable degree. Compensation for total transit time of the polarised relay at all signal amplitudes would result in a virtually distortionless impulsing system. Recent investigation has indicated that the compensation for total transit time at all amplitudes is a possibility.

Thus it would appear that " distortionless " (*i.e.*, to close limits) impulse repetition by direct acting means, without storage or correction, except for transit time compensation, is a possibility, and this principle is now being investigated as the basis of development for a new long distance D.C. impulsing system.

The known techniques, and many new proposals, have been examined, and it has been concluded that four new proposals:—(1) Double Counter E.M.F., (2) Single Counter E.M.F. (Valve scheme), (3) Double Flux Commutation and (4) Single Commutation D.C. Impulsing already described, more nearly meet all requirements. It should be noted that none of these schemes requires, essentially, the phantom of 4-wire circuits to be extended to the automatic equipment when signalling within quad on non-group-worked 4-wire amplified audio cables.

These four proposals have been investigated with the view to selecting one for development as the future standard long distance D.C. impulsing system to be adopted by the Department. The Single Commutation D.C. impulsing system has been so selected by virtue of its superior impulsing performance and extreme simplicity. The impulsing performance is virtually distortionless on circuits up to 100 miles of 20 lb. 4-wire amplified line. Final development of the Single Commutation system is now proceeding rapidly.

For the shorter D.C. links it would be desirable to introduce the transformer type transmission bridge in the usual outgoing junction relay-set equipment, and utilise the loop-disconnect impulsing principle because of its simplicity and not requiring an incoming relay set. Condenser type junction relay-set equipment is, however, existent in the field, and as it is not economic wholly to replace this equipment, the best that can be done at this stage is to ensure that new equipment is of the transformer type. This requires the solution of the problem of inter-working between condenser and transformer type equipments, and this is being actively studied. It should be appreciated, however, that the inter-working difficulties would be largely mitigated if all existing condenser type equipment incorporated the " two stage drop back " feature.

It has been realised, however, that for some considerable time to come the bulk of the local junction network will incorporate condenser type bridge equipment, and account has been taken of this fact in the determination of the proposals to meet future dialling requirements. These proposals for the national network may be summarised as follows:—

Zone-Zone Circuits.

V.F. impulsing.

Zone-Group (and Group-Group) Circuits.

The method of impulsing will depend on the type of line plant provided, whether carrier or audio. The requirements will, in some links, be met by the new Single Commutation D.C. Impulsing system having " distortionless " impulse repetition. On other links it will be necessary to adopt V.F. impulsing.

Group-Minor and Minor-Dependent Circuits.

Loop-disconnect impulsing is used throughout on local junction networks, *i.e.*, in multi-exchange and multi-metering areas. On account of the simplicity, and that the amount of impulse distortion is tolerable providing the input is no worse than that permitted by the normal dial tolerances, it is considered that there is no compelling need to modify loop-disconnect impulsing for these networks, except for the possibility of incorporating transformer type bridges in new junction equipment. This applies to the majority of Group-Minor and Minor-Dependent links which are largely incorporated in local junction networks. There will be links which will fail with existing loop-disconnect impulsing, and the new long distance D.C. scheme Single Commutation D.C. will then be necessary.

17. CONCLUSION.

The range of the usual " loop dialling " with condenser type transmission bridges is extremely limited, and without impulsing aid the method is inadequate to meet modern D.C. impulsing requirements. Light gauge 4-wire amplified circuits introduce further problems, and the condenser type bridge was never really designed for application to such circuits.

Impulse regeneration solves the difficulty to a certain extent, but in certain circumstances the delays involved make this impulsing aid somewhat unattractive. The transformer type transmission bridge with high-speed impulsing relay is an undoubted advance on the condenser bridge, and with its application the necessity for impulse regeneration would not be so acute.

The " loop-disconnect " technique is unsuitable for long distance D.C. impulsing, and another method, which requires the impulsing battery to be located at the sending end, is called for. Thus, both outgoing and incoming junction relay-sets are required for long distance D.C. working as compared with the one, outgoing, relay-set required for loop-disconnect impulsing over the shorter lines.

It only remains to express the hope that the paper has led to a clearer understanding of the D.C. impulsing problem and an appreciation of the difficulties.

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