No. 193

The Institution of Post Office Electrical Engineers.

Improvements in Telephone Signalling

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

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A Paper read before the London Centre of the Institution on 7th February, 1949, and at other Centres during the Session.

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1. INTRODUCTION.

The post-war period has seen a large increase in local and trunk traffic, manual switching of which involves the procurement and training of additional staff together with increased manual board provision. At the same time, post-war shortage of accommodation does not permit of extensions to manual boards, and while it may always be possible to maintain the service by devising expedients employing manual switching, it is obviously undesirable in present circumstances to have to increase the demand for manual labour.

An urgent need therefore exists for the extended use of rapid operating methods in order to give manual board relief. Most relief will undoubtedly arise from increased mechanisation of local and trunk networks, and it is the main purpose of this paper to discuss the signalling problems which this proposal introduces.

Consideration is given to the signalling requirements of local and trunk networks in order that tandem dialling may be extended, and mention is made of signalling requirements set by changes in transmission practice. Existing systems are seen to be capable of improvement to meet some of the tandem dialling requirements of the immediate future.

Consideration is then given to the known limitations of present D.C. and A.C. signalling systems. Improvements in loop/disconnect working are mentioned and a new system of long-distance D.C. (L.D.D.C.) dialling is described. The V.F. signalling problem is outlined in its various aspects and alternative V.F. signalling techniques are suggested. The design of a system of V.F. signalling in which speech and signalling paths are separate is then discussed.

2. PRESENT SIGNALLING REQUIREMENTS.

2.1. Local Networks.

Tandem dialling in local networks is restricted by the characteristics of impulse repeating equipment. Both the number (and overall resistance) of tandem connected junctions and the maximum resistance of individual junctions are restricted. With modern equipment the former restriction has been considerably eased but the latter remains, and intermediate junctions are limited to 800 ohms.

Consideration of the characteristics of 10, 20 and 40 lb. loaded junction cables shows that the transmission equivalent at 800 c/s and the loop resistance (including loading coils) are both very nearly inversely proportional to the conductor weight, and hence are directly proportional to each other, the approximate relationship being 250 ohms per 1 db. Clearly a dialling limit of 800 ohms is inadequate from the transmission aspect, and while it may be possible to meet signalling limits by bunching conductors, or laying heavier gauge conductors, such measures are either technically or financially unsound. In order to permit tandem dialling over 6 db. junctions provided on the most economic line plant the signalling limit of tandem dialling junctions should be raised to 1500 ohms. This limit can be met by the use of impulse regenerative auto-auto relay sets, since the A relay, which carries only one contact, has a lower operating current than the 2-contact A relay of non-regenerative equipment. But if the use of regenerative auto-auto relay sets is to be avoided it is essential that the non-regenerative equivalent should have a signalling limit of at least 1500 ohms. To provide some margin against variation in transmission standards a limit of 2000 ohms is desirable.

Amplified junctions present an impulse distortion problem. Use of the phantom of the quad for the signalling path keeps the resistance down, but leads to high mutual capacitance. With loop/disconnect impulsing the distortion introduced by lines of this type can be minimised by raising the release current of the A relay, but, since this requirement conflicts with that of operating over 1500 ohm or 2000 ohm lines, it is clearly impracticable. The requirements of amplified lines can best be met by an L.D.D.C. system of the type described later.

2.2. Trunk Network.

All zone-zone links will be equipped with V.F. dialling systems, but on zone-group and group-group links L.D.D.C. systems are likely to be used whereever audio cables exist. Both systems are at present in use ; 2 V.F. at zone centres, L.D.D.C. at certain group centres in the London Toll area. Battery dialling is also used on audio circuits.

The extension of 2 V.F. working to group centres has been delayed by lack of accommodation and power supply and must await the introduction of V.F. signalling equipment having low power consumption and requiring small space. The usefulness of this step is dependent on the solution of the problem of dialling over 2 V.F. links connected in tandem. This is discussed later.

Trunk circuits used for D.C. dialling are invariably amplified and on account of the high capacitance of the signalling path battery dialling is unsatisfactory. L.D.D.C. dialling systems, which are specially designed to operate over 4-wire amplified circuits will replace battery dialling.

Both the present L.D.D.C. system and the 2 V.F. system are unsuitable for 2-link tandem dialling without the aid of regenerators and schemes for providing immediate manual board relief at zone centres will entail the use of mechanical impulse-regenerators at tandem switching points. But the V.F. and L.D.D.C. dialling systems to be used for further mechanisation of the trunk network should, if possible, be capable of providing straightforward tandem dialling facilities. Mechanical impulse regenerators are not regarded as desirable features of a mechanized switching system. As compared with straightforward methods of impulse repetition they introduce an inherent delay in call setting and owing to the relative intricacy of the mechanism (electrically and mechanically) are likely to prove a potential source of weakness in a mechanised trunk system.

2.3. Transmission Developments.

Some reference to signalling requirements dictated by transmission developments seems appropriate.

It has been authoritatively stated, that, for many years to come, our development needs will be met by the extended use of wideband systems, in which case it would appear that no fundamental change of signalling technique is called for. But in the event of novel transmission techniques, such as those used in the Vocoder, finding practical application, there will arise some very interesting signalling problems, which as far as the authors are aware have not yet received serious consideration.

Such changes in transmission practice as can be foreseen are likely to require the use of A.C. signalling methods where in the past D.C. methods have been adequate. Provision of service to island or isolated subscribers and communities by means of radio channels or carrier channels on power mains is now under consideration. For subscribers' circuits simple devices using the two carriers may suffice to give the equivalent of calling and clearing signals in both directions, but, if U.A.X. junction circuits are required to be provided by similar means, more complex A.C. signalling arrangements would be required to give the usual discriminating signals.

A change from D.C. to A.C. signalling is also required in audio circuits, which, for protection reasons, are required to be equipped with isolating transformers. The need for D.C. isolation arises from the risk of induction of high longitudinal voltages by fault currents in parallel routed power lines, normal methods of protection often being inadequate on account of high earth resistivity.

3. IMPROVEMENT OF EXISTING SYSTEMS.

Present requirements will be met in full when various signalling improvements, at present in various stages of development, become available. In the meantime it is necessary to consider what improvements are possible with existing systems. The improvements sought are mainly those affording better tandem dialling facilities, which, while providing the means of obtaining valuable manual board relief, do not prejudice in any way the introduction of preferred new systems.

3.1. Loop/Disconnect.

In any tandem dialled connection the objective is operation of a selector in a remote exchange. The impulsing requirements of this selector determine the distortion margin, which in turn determines the number or length of individual junctions permissible. A convenient manner of expressing distortion margin is by means of a target diagram. Fig. 1 shows target diagrams for 3,000 type and 2,000 type equipment.

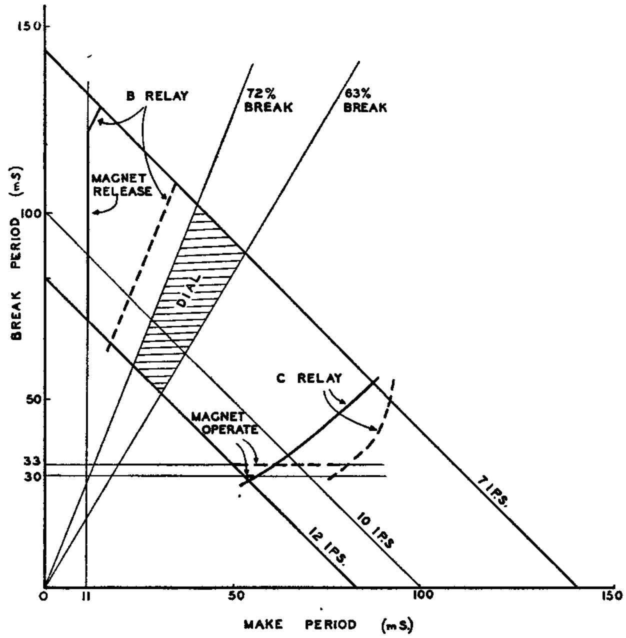


FIG. 1.—SELECTOR TARGET DIAGRAMS.

The superior impulsing performance of the 2,000 type selector equipment over the range 7—12 i.p.s. enables better tandem dialling limits to be specified for traffic terminating in 2,000 type exchanges, and is due to the use of improved impulse stepping and control circuits. The difference in this latter respect between 2,000 type and 3,000 type equipment lies in the B relay and Magnet circuits. In 3,000 type equipment, Fig. 2(*a*), they are divorced, but in 2,000 type equipment, Fig. 2(*b*), they are associated with mutual benefit.

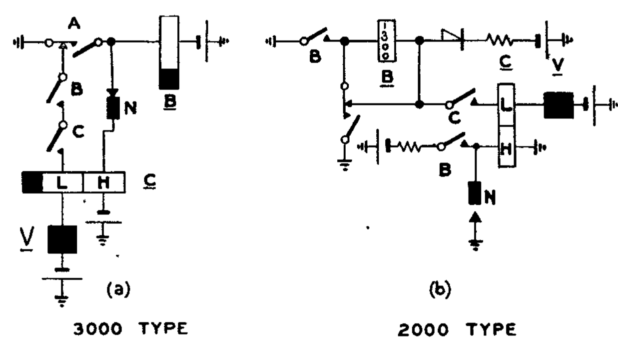


FIG. 2.—SELECTOR IMPULSING ELEMENTS.

In Fig. 2(*b*) energisation of relay B in series with the magnet results in leak current flowing through the latter with consequent reduction in operating time. There is also some increase in releasing time, but this is offset by improved magnet design. The rapid flux rise in the B relay during short energising periods results in improved impulse holding performance as compared to an equivalent slugged relay. Acceleration of flux rise results from dissipation, in the B relay coil, of the back e.m.f. from the magnet when contact A operates.

Improved impulsing performance permits more impulse repetitions but does not materially influence the maximum resistance of individual junctions in a tandem connection. Junctions preceding auto-auto relay sets are limited to 800 ohms by called subscriber answer pick-up[1]*, *i.e.*, failure of the A relay to operate in series with the 800 ohm D and I relays of the holding loop, at the distant end of the junction, after reversal of potential. With the introduction of improved designs for D and I relays having combined resistance 400 ohms and sensitivity adequate for 2,000 ohm junctions it will be possible to effect considerable improvement in junction limits; 800 ohm intermediate junctions may become 1,200 ohms and 1,500 ohm terminal junctions may become 2,000 ohms. This improvement in the maximum resistance of tandem dialling junctions will, in many cases, avoid the need for regenerative auto-auto relay sets.

3.2. Assessment of Impulsing and Signalling Limits.

It has been the practice in this country to assess impulsing and signalling limits on the basis of simultaneous existence of adverse tolerances on most factors influencing the operation of equipment. The stringency of this method is often criticised on the basis that the probability of individual factors being adverse is relatively small and the overall probability of all factors being adverse simultaneously is almost negligible. An advantage claimed for assessing junction limits by what may be called a " probability technique," as compared to an " adverse technique," is that greater junction resistance limits, together with more impulse repetitions, would be possible with the equipment now existing. To assess the validity of this claim it will be necessary to collect much data on " as found " adjustment and performance of equipment in all types of automatic exchanges.

Battery voltage is one of the factors influencing junction limits. The usual adverse tolerances are 46—52 volts, but at exchanges equipped with Divided Battery Float power plant[2] a much smaller voltage range is maintained so long as reliable mains supplies are available. The limits of loop/disconnect junctions incoming to D.B.F. exchanges may safely be increased by approximately 12%, but uncertainty regarding winter power supplies makes this step unattractive at present.

3.3. 2 V.F. System.

Hitherto 2 V.F. routes o/g from zone centres have been accessible only from manual boards, to provide the facility of single link trunk dialling plus limited access into remote loop/disconnect networks. Provision of two link trunk dialling by permitting selector level access into o/g 2 V.F. routes with tandem dialling from group centres within loop dialling range might appear simple in view of the existence of a selector level path of entry in existing o/g relay sets. But the difficulties, which, in the past, have prevented this are as follows:—

(*a*) The long seizure time of the 2 V.F. link exceeds the time available with inter-digital pauses from operators' dials.

(*b*) The connection in front of a 2 V.F. link of a loop/disconnect junction introduces additional impulse distortion which reduces the already limited access to remote non-director networks. Further, if the preceding link introduces negative distortion (loss of make period) there is serious risk of transient interference within the 2 V.F. link causing additional and intolerable distortion.

These difficulties may be overcome by connecting auto-auto relay sets with a regenerator in front of 2 V.F. o/g relay sets, and successful field trials on these lines have been conducted to give 2 trunk link tandem working on the routes Bath-Bristol-London.

A trial has also been made of a digit absorbing device in place of the regenerative relay set. Whilst this device provides adequate seizure time it does not assist impulsing. Further, group centre operators are required to dial a non-selective digit. The regenerator arrangement is therefore preferred.

Unfortunately the simple expedient of connecting a regenerative auto-auto relay set in front of a 2 V.F. o/g relay set is not suitable for two link trunk dialling where the first link is 2 V.F. Surges, generated in the regenerative auto-auto relay set, may cause misoperation of the 2 V.F. equipment. The trouble arises when the originating operator dials slowly or hesitantly and allows the regenerator to discharge its stored impulses before dialling is complete. In dropping back from the pulsing-out condition the regenerative auto-auto relay set transmits a surge over the speech path. The surge may be tolerated on proceeding loop/disconnect circuits, but on 2 V.F. circuits it will momentarily paralyse the receiver and may cause a succeeding impulse to be lost.

By including the regenerator as part of a redesigned o/g 2 V.F. relay set, the surge difficulty is removed, the cost reduced and transmission improved. 2 V.F. equipment of this type which will shortly be available for new work is capable of providing full tandem dialling facilities at automatic trunk switching centres. Its main advantages may be summarised as follows:—

(*a*) 2 V.F. links may be preceded by links of any type including loop dialling links of up to 1,500 ohms resistance.

(*b*) The tandem dialling range into the remote local network is quite independent of the type of link which precedes the 2 V.F. link.

(*c*) Any number of regenerative 2 V.F. links may be connected in tandem.

(*d*) The transmission of impulses over the 2 V.F. link may be delayed until adequate time has been allowed for seizure sequences.

A further feature of the new 2 V.F. equipment will be the introduction of an improved receiver having low power consumption, using preferred valves, and occupying less space than the present P.O. standard.

* Numerical references are to the Bibliography at the end of the Paper.

3.4. Generator Signalling.

Equipment has been designed to permit generator signalling from selector levels on routes o/g to sleeve control manual boards. The arrangement has been conceived as a temporary measure pending conversion to dialling, and for this reason elaboration and complexity have been avoided by omitting facilities and safeguards usually provided on automatic equipment. The scheme merely provides for transmission of a long pulse of ringing current (or its equivalent) when the circuit is seized. An answering supervisory signal is returned on the dialling circuit immediately on seizure and is removed for the duration of any backward recall ring from the manual end of the circuit. Backward guard is not provided and follow on calls give rise to the same conditions as on circuits between manual boards.

4. LIMITATIONS OF EXISTING SYSTEMS.

The broader limitations of present systems, their effect on the provision of dialling facilities and means for alleviating or removing these limitations have already been discussed. But in order better to appreciate the full advantages to be gained from the introduction of new dialling systems some more detailed consideration is necessary.

4.1. Loop/Disconnect.

In current practice widespread use is made of condenser type bridges in auto-auto relay sets and similar impulse repeating equipment. This type of bridge is quite cheap and introduces only small transmission loss, but it has certain limitations both from the signalling and transmission aspects. Its signalling limitations have been described in detail elsewhere[1] and present considerations will be limited to questions of transmission. As is well known, the condenser bridge has the property of passing longitudinal line currents and when used on junctions exposed to interference allows the magnitude of transverse noise voltages to be dependent on the degree of balance maintained in associated lines or equipment. Power lines and electric traction systems have long been sources of noise induction ; the latest offenders are our own power carrying coaxial cables. Condenser type bridges may themselves act as sources of longitudinal induction as, for instance, in loop-dialling circuits when the back e.m.f. from a distant A relay causes earth current to flow via one wire of the junction while the other is broken by the local impulse repeating contact. In the condenser type bridge these surge currents flow to earth via the two condensers and the windings of adjacent or preceding A relays. Hence, apart from producing crosstalk, they are also responsible for distortion of waveform during impulsing. It is this distortion of waveform on one link by surges from adjacent links, that makes it impossible to predetermine the impulsing performance of tandem routings with condenser bridges.

4.2. L.D.D.C.—Differentiated Current System.

This system has been adequately described elsewhere[3]. It has given very good service since it was first introduced on a large scale in 1945, but the following limitations of the system must be recognised:—

(*a*) Any interfering signal is differentiated in the same way as signalling currents, and since the signalling voltages applied to the grid of the relay operating stage are dependent both on frequency and magnitude of the interference, the possibility of false operation is greater than with a permanent current system in which the magnitude only of the interference is of any consequence.

(*b*) Arising out of (*a*) it is necessary to extend the signalling wires from the phantom of a 4-wire audio circuit direct from the line transformers to the relay set instead of via the 2-wire side of the line terminating unit. The reason for this lies in the liability to false operation from dialling surges transmitted over the side circuit (speech path) when these are amplified, and allowed to recombine with the signal received over the phantom circuit (signalling path).

(*c*) The arrangements employed for switching the impulsing elements into circuit on seizure of the link lead to a seizure time almost comparable to that of the 2 V.F. system. This feature makes the system unsuitable for straightforward tandem dialling.

(*d*) The overall distortion of one link may be as high as + 5 m/s so that, when two links are connected in tandem, impulse regenerators must be introduced at the tandem switching point in order to permit a reasonable measure of dialling access into the distant loop/disconnect network. Inclusion of the regenerator at tandem centres is also necessary to overcome (*c*) above.

(*e*) Additional battery supplies (+ 50 V) are required for the valve included in the impulse receiving element.

4.3. 2 V.F. System.

The present 2 V.F. system is applied single V.F. link working only with operator control. Subsequent D.C. links are possible but preceding links, D.C. or V.F., are not unless various precautions are taken in regard to the 2 V.F. system being a tandem link.

4.3.1. *Operational Limitations.*

When 2 V.F. working was introduced the " on demand " provision of line plant prevented tandem dialling on the trunk network. But with provision on a " no delay " basis more emphasis is placed on the operational limitations of the 2 V.F. system. These may be summarised as follows:—

4.3.1.1. *Seizure Time.*

The long seizure time prohibits seizure during normal dial inter-digital pauses. Fig. **3** shows the seizure sequence and it will be seen that the incoming selector seizure is not initiated until the V.F. seizure pulse has ceased. When seizing from selector level on tandem working the selector relay and rotary hunt times must be added to T. T exceeds the local D.C. seizure time by a period $t_1 + t_2$ approximately, and when it is realised that local D.C. seizure is sometimes difficult during dial inter-digital pauses, the 2 V.F. difficulty is clear.

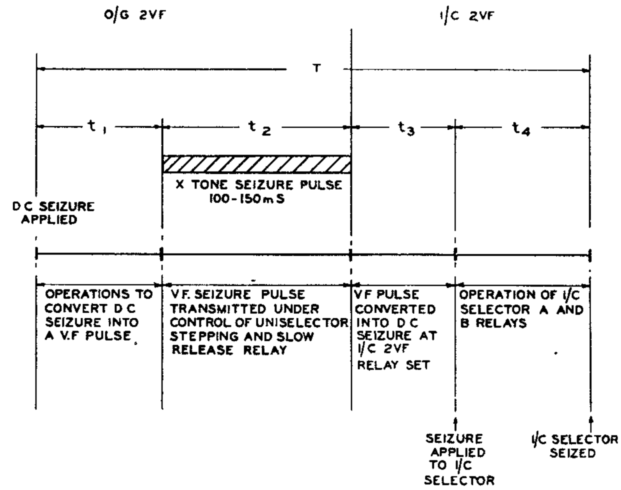


FIG. 3.—PRESENT 2 V.F. SYSTEM. SEIZURE SEQUENCE.

4.3.1.2. *Impulse Distortion.*

The impulse distortion tends to limit tandem working. The impulsing performance of the early type 2 V.F. receiver is poor, that of the diode stabilised type is reasonably good, but the distortion of the initial D.C. repetition (3,000 type relay) in the outgoing relay set tends to be high.

4.3.1.3. *Dependence of Speech on receipt of Answer Signal.*

The present 2 V.F. system is dependent on the receipt of an answer signal to set up bothway speech conditions. For certain operator services an answer signal is not normally available and arrangements must be made to give the answer which is not always convenient. The difficulty arises due to the possibility of D.C. dialling surges (or other interference) transmitted before the true V.F. impulse (Fig. 4) energising a distant V.F. receiver on either the guard or signal circuit. The true V.F. impulse following up may thus find the receiver in an energised state and distortion results. Also, interference in the forward direction may energise an echo-suppressor at the incoming end which may block a return signal such as answer.

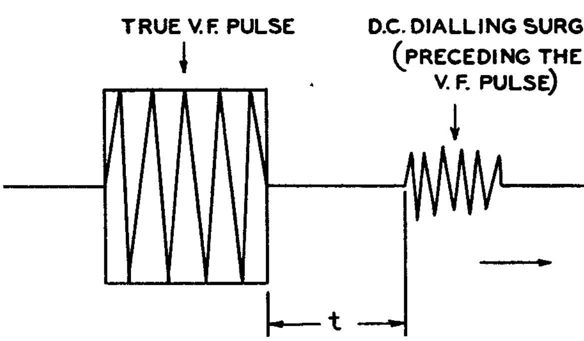


FIG. 4.—PRESENT 2 V.F. SYSTEM. SURGES PRECEDING A TRUE V.F. IMPULSE.

The present system overcomes the difficulty by a line split and stopper valve arrangement in the outgoing relay set (see Fig. **5**). Contacts CT split the line but tones and speech may be transmitted in direction B to A via the stopper valve SV functioning as a simple one way amplifier. Transmission A to B is prevented by the line split. To set up bothway speech conditions a distinctive signal is required and the answer signal is used for this purpose.

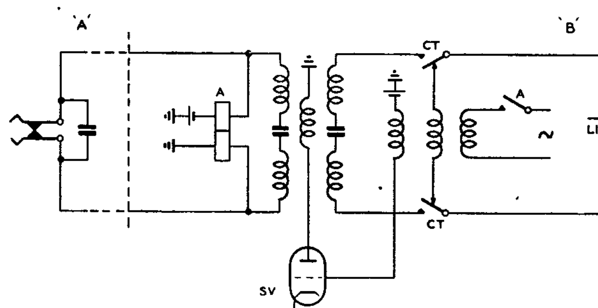


FIG. 5.—PRESENT 2 V.F. SYSTEM. STOPPER VALVE FEATURE.

4.3.2. *Complexities.*

In addition to the operational limitations mentioned above the opinion is sometimes held that the 2 V.F. system is somewhat complex in regard to the following points:—

4.3.2.1. *Pulse Type Signalling Code.*

A pulse type signalling code involves sequencing and timing arrangements. Further, complexity arises in the conversion of the pulse signals to "permanent" conditions. The necessity for the pulse code will be discussed later.

4.3.2.2. *Signal Imitation.*

As the 2 V.F. system is signalling on speech path, precautions must be taken to minimise signal imitation by speech. This leads to complexities such as repeated signals, two tone signals and signals maintained for a certain time before being effective. Also it is necessary to incorporate a guard feature in the receiver.

It should be mentioned at this stage that the use of two frequencies is advantageous in regard to signal imitation compared with a single frequency. Also the two frequencies permit flexibility in regard to the number of signals which may be given without undue complexity. There are other factors influencing this problem and these will be discussed later.

While various limitations have been discussed with reference to the present 2 V.F. system, it may be mentioned that these are not regarded as fundamental. A signalling on speech path V.F. system can be designed to meet all the requirements of the trunk network.

5. IMPROVED D.C. SIGNALLING SYSTEMS.

Developments have proceeded on the general lines suggested in a recent paper read before this Institution[1]. It is recalled that an important feature of the proposals made therein was the use of transformer type transmission bridges. Arguments in favour of this bridge have also been stated on general transmission grounds. As a first step an improved 1:1 transformer (3/185A), having split balanced windings, and capable of carrying 150 mA D.C., has been developed. Its insertion loss between non-reactive 600 ohm terminations is only 0.45 db. at 400 c/s and 0.2 db. above 1000 c/s. This improvement in performance as compared with earlier transformer bridges is attributable to its conception as a high pass filter when used with 2 μF centre point condensers and signalling relays of high inductance (1H). Transmission performance tests carried out on subscribers' lines and junctions show it to have a better performance on unloaded than on loaded lines.

5.1. Loop/Disconnect with Transformer Bridge.

The signalling advantages of this type of bridge are bound up with the use of high speed type impulsing relays. These are inherently of small size, and to obtain adequate overload protection, 50 + 50 ohm windings with ballast feed must be used. Current sensitivity of the relay is therefore limited and with the present P.O. standard high speed relay the maximum junction resistance that can be met with an 800 ohm D and I holding loop at the distant end is 1,200 ohms. As already explained this is inadequate to meet present needs, but the recent development of a slightly larger high speed relay has led to the removal of this limitation. The new relay has become known as the 2-contact high speed relay and while its speed of operation is inadequate for such applications as tripping the drive of motor uniselectors its high speed characteristics are ample for impulsing purposes. A larger coil assembly should permit it to function with a preceding loop resistance of 2,400 ohms, allowing 2,000 ohm junctions with 400 ohm holding loops. A view of this relay is given in Fig. **6**.

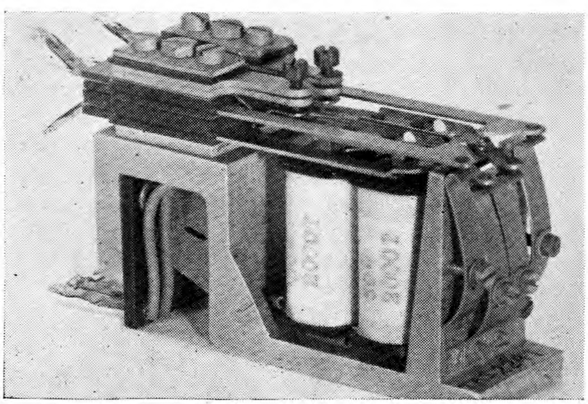


FIG. **6**.—TWO-CONTACT HIGH SPEED RELAY.

It should be possible with auto-auto relay sets employing relays of this type to connect two 2,000 ohm junctions in tandem. On shorter junctions the ability to predetermine impulse distortion should enable multi-link connections to be planned to take full advantage of the distortion margins available between the impulse source and the requirements of the objective final selector. While loop/disconnect with transformer bridge has distinct advantages, its disadvantages should be understood. A slightly greater transmission loss may be introduced with certain combinations of line plant. From the switching aspect difficulties may arise when interworking with existing equipment since surges which are tolerable with condenser bridges may cause false operation of high speed line relays used in transformer bridges.

5.2. L.D.D.C. Single Commutation System.

This new system of L.D.D.C. dialling (S.C.D.C.) will supersede the present Differentiated Current System since, while having none of its known disadvantages, it is by comparison more simple and occupies less space. Further, it provides more signalling facilities and has an extremely good impulsing performance which may render the use of impulse regenerators unnecessary.

It is so called because the sending-end battery is in effect reversed in polarity or commutated by a single change-over contact. Double current effect is thus obtained. The system is based on a balanced bridge principle and permits the simultaneous use of independent backward and forward signals, *i.e.*, duplex signalling. The dialling range is extended by including the signalling apparatus in line terminations designed to improve the received current waveform, and thus permit the steady state current value to be attained in a shorter time.

5.2.1. *Duplex Signalling Principles.*

Fig. **7** shows the principle of the system. R represents the line, Z the windings of the transformer

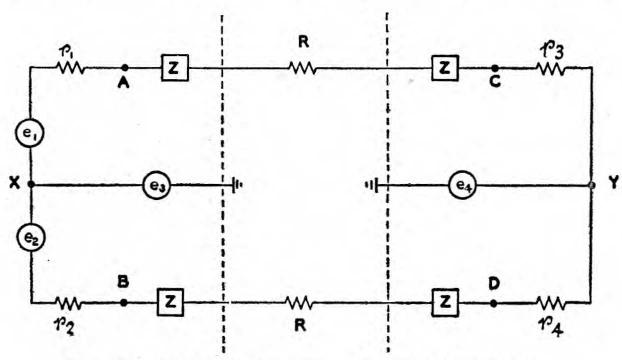


FIG. **7**.—S.C.D.C. SYSTEM. DUPLEX SIGNALLING.

bridges at each end and r_1 r_2 r_3 r_4 the windings of signalling relays. Series sources of signal current e_1 e_2 complete the line loop circuit and sources e_3 (or e_4) have earth returns. The arrangement is balanced with respect to earth. It is seen that the circuit resembles a Wheatstone Bridge. Any circuit change such as the connection of a resistance or short circuit across equal potential points such as AB, CD, or a reversal of polarity of both e_1 and e_2 cannot affect the potential between points X and Y and hence cannot affect the earth current flowing between X and Y, although the distribution of current between the line wires may be modified. Hence the conditions for pure loop signalling (*i.e.*, no change in earth current) are established. Potential e_3 or e_4 will produce line current of equal magnitude in each wire flowing in the same direction. It follows that any change in e_3 (or e_4) or a disconnection between X and Y will produce similar effect in each wire. Hence conditions for pure earth signalling are established. The potential across CD, which is the algebraic sum of the voltages across the balanced series resistors r_3 r_4 is zero for earth currents and finite for loop currents while the algebraic differences are respectively finite and zero. The same is true of points AB and resistances r_1 r_2.

Now r_1 r_2 are balanced windings of a line relay (and r_3 r_4 the windings of another). If the windings be connected in series aiding in a loop sense the relay will respond only to loop currents (sum of voltages finite) and not to earth currents (sum of voltages zero), but if connected in series opposition in a loop sense will respond to earth currents (difference of voltages finite) and not to loop currents (sum of voltages zero). Pure loop signalling currents and pure earth signalling currents can therefore be detected independently.

The simplest arrangement uses loop signals only from the calling end and earth signals only from the called end.

5.2.2. *Practical Form of the System.*

Fig. **8**(*a*) shows the practical arrangement of the signalling and impulsing element. It provides for double current loop signalling by using a single battery −E and a single change-over contact HSA. Relays DP and IP with line windings 1 and 2 connected in series opposition are non-inductive, and thus non-responsive to the loop current, but are responsive to earth current. Polarised relay AP at the i/c end with line windings 1 and 2 connected series aiding responds to loop currents in either direction transmitted by contact HSA but does not respond to earth currents.

If relays DP and IP are of normal type they will respond to earth return currents in either direction, but to obtain adequate sensitivity, and in certain applications to discriminate between different earth signals, these relays are required to be polarised. Relay AP is always fluxed and during idle periods is energised to the break direction (*i.e.*, released position) by line current which flows permanently with the HSA contact in the unoperated position. Relays DP and IP are fluxed only while an earth or battery connection is applied to the centre point of AP at the i/c end, and in order to detect the absence of earth current, in addition to presence and reversal of earth current, it is necessary to add locally energised biasing windings to both relays DP and IP.

The arrangement is balanced, but a transitory earth current will flow tending to produce crosstalk during the transit time of contact HSA which should be kept short.

5.2.3. *Facilities Provided.*

The following facilities, some of which are quite novel, are provided by the S.C.D.C. system:—

(*a*) Forward call and clear.
(*b*) Impulse repetition.
(*c*) Forward operator recall.
(*d*) Busy flash.
(*e*) Backward answer and clear.
(*f*) Backward release guard.
(*g*) Backward busying.
(*h*) Bothway working.

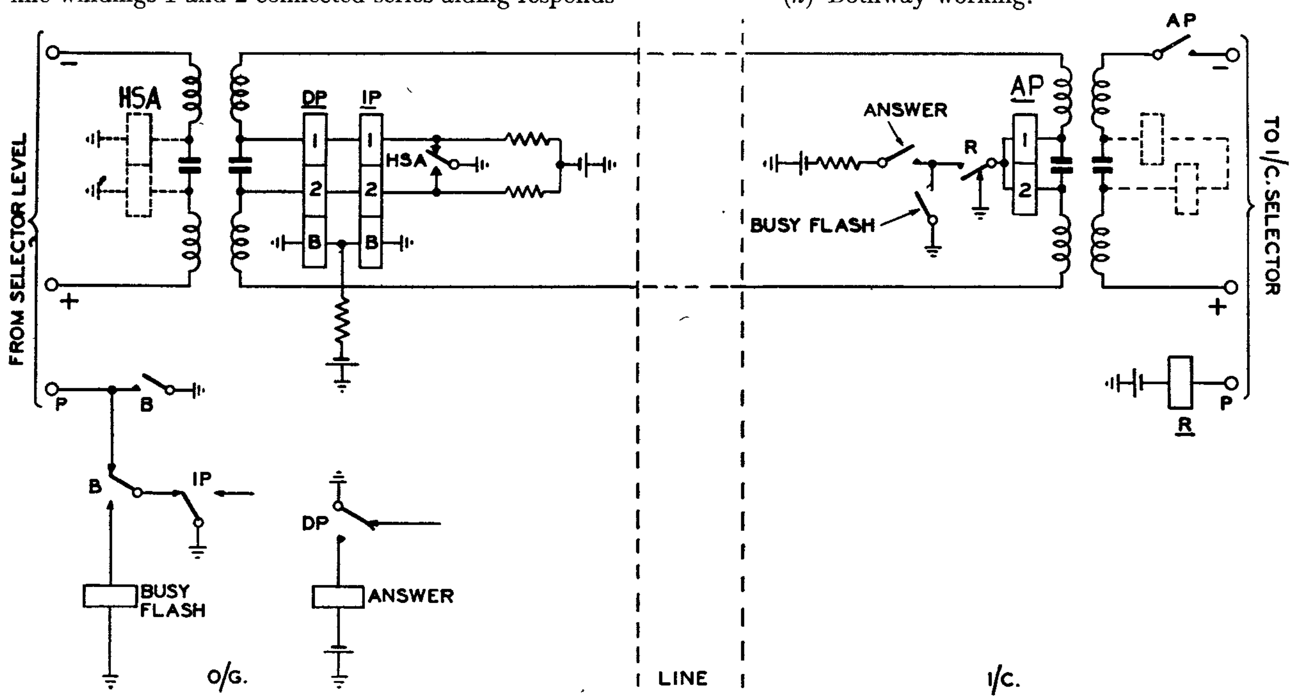
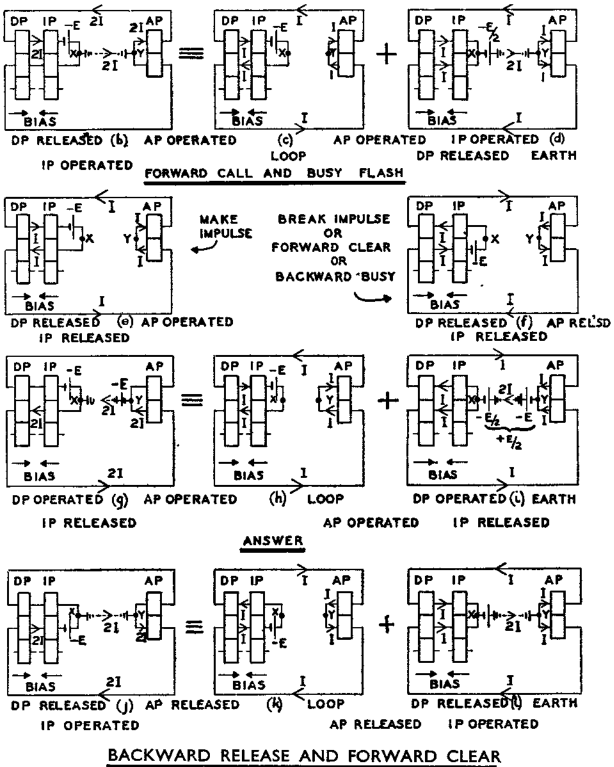


Fig. 8(*a*).—S.C.D.C. System. Signalling Elements.

(*a*) *Forward Call and Clear* are loop signals applied by contact HSA. Prior to forward call the circuit is in the idle condition in which state the signals present are forward clear and backward release as shown in Fig. **8**(*j*). Current 2I flows in one wire to hold AP in released position, but the change to the calling condition causes this current to flow in the other wire.



FIGS. 8(*b* TO *l*).—S.C.D.C. SYSTEM. ANALYSIS OF FIG. 8(*a*).

This change shown in Fig. **8**(*b*) will not affect relays DP and IP (compare Figs. **8**(*d*) and **8**(*l*) but will operate relay AP (Fig. **8**(*d*)). AP seizes the selector and operates R (Fig. **8**(*a*)) which removes the earth from the centre point of AP and so releases IP to give a backward busying condition which is maintained so long as the i/c selector is off normal or otherwise engaged. The forward clearing signal given in the absence of busy flash or backward answer conditions is equivalent to a break impulse (Fig. **8**(*e*)), but if given in the presence of busy flash is as shown in Fig. **8**(*j*). The condition of forward clear in the presence of an answer signal is not shown as a separate figure but will be understood.

(*b*) *Impulse Repetition* is obtained by commutating the loop battery at contact HSA. This results in reversals of loop current and causes AP to respond in a loop sense in double current manner. The condition of a make impulse is shown in Fig. **8**(*e*) and a break impulse in Fig. **8**(*f*). IP and DP are resistive to impulsing and do not respond.

(*c*) *Forward Operator Recall* will be given by operation of the position circuit "Ring Call" key, which by circuit arrangement, may place the HSA contact of an o/g sleeve control relay set under the control of locally generated impulses. Key controlled trains of impulses would then be transmitted via intermediate links and eventually identified in a suitably arranged assistance or other manual board circuit to which the automatic equipment gives access. Intermediate links must therefore be capable of transmitting impulses irrespective of the existence of the answering supervisory signal. The condition of impulsing in the presence of a backward answer signal is not shown but will be understood.

(*d*) *Busy Flash* is signalled by applying an earth to the centre point of AP (point Y in Fig. 8(*b*)) causing current 2I to flow in the earth and one wire. Prior to the connection of earth, point Y (Fig. **8**(*c*)) is at potential $-E/2$ reference earth zero, and loop current I flows in each wire to flux both windings of relay AP. If now point X (zero) and point Y ($-E/2$) are joined via the earth by applying a connection at Y the current in the earth path will flow from the high potential point X to low potential point Y. This current in the earth path may be considered as due to an assumed source of current $-E/2$ located in the earth path as shown in Fig. **8**(*d*) and as far as the flow of earth currents is concerned Y is at zero potential and X at potential $-E/2$. The earth current 2I therefore flows in the line wires from Y to X and divides equally. The current I flowing in each winding fluxes DP and IP but not AP. Fig. **8**(*b*) is thus equivalent to Figs. **8**(*c*) + **8**(*d*) and the loop and earth current signals may be considered to exist independently.

Bias flux in relay DP is strengthened and its contacts remain open, but the net flux in IP is reversed and its contacts operate. The condition of AP and IP operated with DP released is identical to that existing on transmission of the forward call signal, but the circuit sequences in the o/g relay set arrange for this now to be recognised as busy flash. During the tone period of the busy flash cycle the earth is removed to restore conditions shown in Fig. **8**(*c*) and IP is restored by the bias.

(*e*) *Backward Answer and Clear* is signalled by applying a negative battery $-E^1$ to the centre point of AP (point Y Fig. **8**(*g*)) causing reverse earth current to flow. Consider the case of the busy flash signal in which the point Y was at earth zero potential and the point X said to be at potential $-E/2$, and let Y now be lowered to potential $-E^1$ by replacement of the earth connection by a negative battery $-E^1$. Since points X ($-E/2$) and Y ($-E^1$) are joined via the earth path, the current which now flows in the earth circuit is due to a source of current $(-E/2) - (-E^1) = E^1 - E/2$ and if $E^1 > E/2$ point Y will be at a lower potential than X and current will flow in the line wires from X to Y, *i.e.*, in the reverse direction.

In the particular case of $E = E^1$ we have $E^1 - E/2 = +E/2$ signifying a reverse earth current 2I (Fig. **8**(*i*)). Again this current divides equally, current I flowing in each winding to flux DP and IP in the reverse direction, but not AP which as before is fluxed by the loop current in each winding (Fig. **8**(*h*)). Fig. **8**(*g*) is therefore equivalent to Fig. **8**(*h*) + Fig. **8**(*i*) and the loop and earth current signals may be considered to exist independently in this case also.

Bias flux in relay IP is strengthened and its contacts remain open, but the net flux in DP is reversed and its contacts operate to repeat the answering supervisory signal. Backward clear is signalled by disconnecting the negative battery at the i/c end to restore DP.

On dialling-in circuits from manual boards it is not necessary to provide distinctive answer and busy flash supervisory signals and unidirectional earth currents may be used.

(*f*) *Backward Release Guard* is obtained by delaying the restoration of the idle circuit condition (IP operated with DP and AP released) until the i/c selector has restored. The backward release signal is then given by restoring the earth connection to the centre point of AP (Fig. **8**(*j*)) which remains held to the break position by loop current (Fig. **8**(*k*)) while IP operates to the earth current (Fig. **8**(*l*)). Operation of IP removes the release guard applied to the o/g multiple (Fig. **8**(*a*)).

(*g*) *Backward Busying* follows simply from (*f*) in that it is necessary merely to disconnect the backward earth signal in order to reintroduce the guard on the o/g multiple. Since this facility is provided by *disconnecting* the earth signal it follows that a circuit will be automatically busied in the event of the junction wires becoming disconnected or the I/C or B/W relay sets being jacked out. The condition is shown in Fig. **8**(*f*).

(*h*) *Bothway Working* may be provided by coupling the i/c and o/g relay sets AB, CD at each end of the circuit via a B/W switching relay set as shown in Fig. **9**. Either A or C (or both) may be arranged for

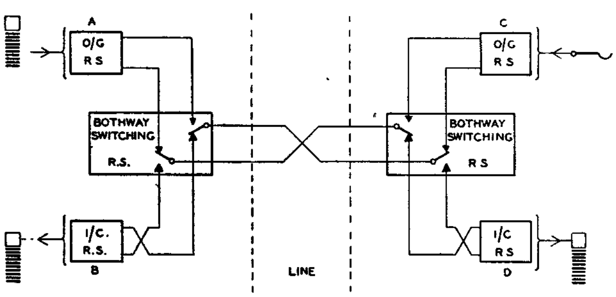


Fig. 9.—S.C.D.C. System. Bothway Working.

operator or selector access, and if one of the o/g exchanges is manual then an i/c relay set such as D may be arranged to utilize the S.C.D.C. elements to provide automatic signalling on i/c calls.

To preserve the basic signalling elements found suitable for unidirectional circuits and to reduce seizure time to a minimum it is necessary for each o/g relay set to be connected via one wire of the junction to its distant i/c relay set. Over this wire AP is held to break and IP to make. The only other departure from the signalling arrangements already discussed, is in respect of the seizure signal which must be an earth return current. A positive battery signal is used to reverse the current in AP, but as the signal is applied in the B/W relay set, relays DP and IP of the local o/g relay set are not included in the earth circuit. Operation of the distant AP causes the second wire of the junction to be disconnected from the i/c relay set at that end. The rapid seizure ensures that unguarded intervals normally associated with B/W working are negligible with this system.

5.2.4. *Extraneous Earth Currents.*

Extraneous and unwanted earth currents are a feature of earth signalling systems. These currents which influence DP and IP, but not AP, may arise from differences in earth potential (E.P.D.) or by induction of alternating e.m.f.'s from 50 c/s power lines.

Considering first the E.P.D. in the presence of an earth signal at Y (Fig. **10**), it will be recalled that,

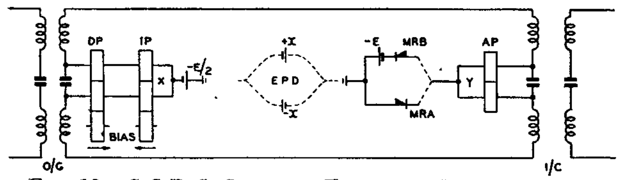


Fig. 10.—S.C.D.C. System. Effect of Earth Potential Difference.

with point Y at zero, a potential $-E/2$ was assigned to the point X. If now point X is regarded as fixed and earth potentials as affecting Y, an E.P.D. $-x$ will lower the potential of Y, and so tend to reduce the potential between X and Y, while an E.P.D. $+x$ will raise the potential of Y and so tend to increase the potential between X and Y. Now if x is negative and equals E/2 (25 volts in a 50 volt system) the potential between X and Y will be $(-E/2) - (-E/2) = 0$ and earth current will cease, but if $x > E/2$ in a negative sense the potential of Y will be lower than X and earth current will reverse in direction. Cessation of earth current results in a *lost* supervisory signal, but reversal results in a *false* signal. The former condition may be tolerated but the latter, which may not, can be prevented by adding the rectifier MRA to the earth connection applied at Y. The rectifier has no effect in the presence of an E.P.D. $+x$ which reinforces the signal.

Consider next an E.P.D. in the presence of the battery signal. Point Y is normally at potential $-E$ and X at potential $-E/2$. An E.P.D. $-x$ will now lower the potential of Y to $-E - x = -(E + x)$ and so increase the potential between X and Y but a potential $+x$ will raise Y to $-E + x = -(E - x)$ and so reduce the potential between X and Y. Now if x is positive and equals E/2 (25 volts in a 50 volt system) then the potential at point Y is $-(E - x) = -E/2$ and the potential between X and Y will be zero and earth current will cease, but if $x > E/2$ then potential of Y will rise above $-E/2$ and earth current will reverse in direction. In this case reversal of earth current may be prevented by rectifier MRB.

Alternatively potentials induced longitudinally into the line wires, as shown in Fig. **11**, will cause earth

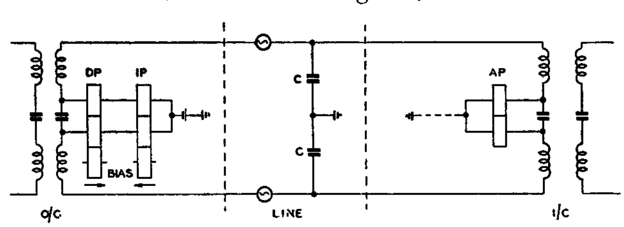


Fig. 11.—S.C.D.C. System. Effect of Induced A.C.

currents to circulate via the wire to earth capacitances even when there is no earth connection applied at the i/c end. Provided the peak value of alternating voltage does not approach the normal signal voltage E/2 no trouble should result.

5.2.5. *Performance.*

Fig. **12** shows the elements concerned with impulse repetition. The overall impulse distortion of one link

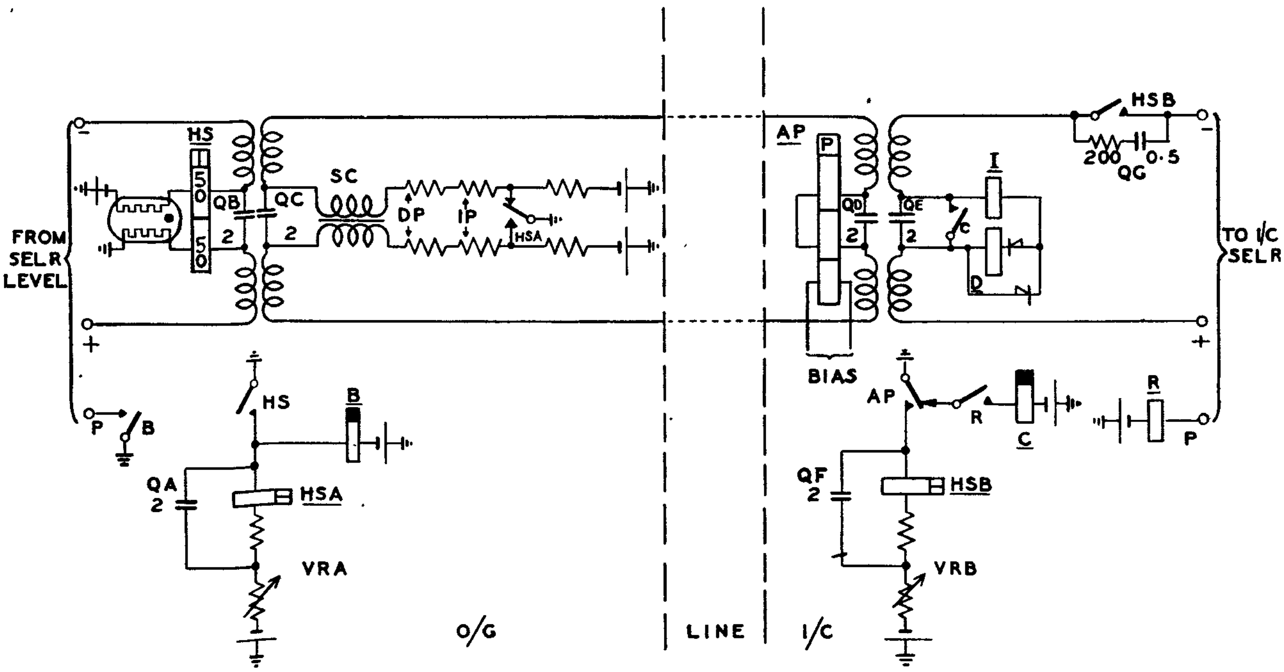


Fig. 12.—S.C.D.C. System. Impulse Repetition.

when connected in tandem with a similar link via an automatic exchange consists of two components:—

(*a*) Distortion introduced by the line including the i/c relay set and measured between the double current sending contact HSA of the o/g relay set and the single current (loop/disconnect) repeating contact HSB of the i/c relay set.

(*b*) Distortion introduced by the exchange repetition measured between the sending contact HSB of an i/c relay set and the repeating contact HSA of an o/g relay set.

5.2.5.1. *Line Distortion.*

Impulse distortion in the line is dependent on:—

(*a*) Received signal waveform.

(*b*) Transit time of AP contact.

These sources of distortion are reduced to a minimum in the following manner.

(*a*) *Improvement in Received Signal Waveform.*

To minimise distortion the received build-up and decay signal waveform must reach steady state to avoid mutual interference between the wavefronts. Mutual interference increases with the time constant of the line and with the reduction of the signal length. The transit time of the receiving relay is least when the operate wavefront slope is steep. Hence improvement would result from a reduction in time for the wavefront to reach steady state and an increase in wavefront slope at the operate point, *i.e.*, the half amplitude value. Such an improvement would permit the use of a greater time constant of line (CRl^2) or a shorter signal. Curve A, Fig. **13**, shows a typical waveform resulting from a rectangular voltage pulse applied to a line of time constant $T = CRl^2$ short circuited at the receiving end. The waveform is not symmetrical about the half amplitude value and maximum slope occurs at a point C, which is not the half amplitude point. The slope at the half amplitude value is not rapid and steady state is reached in time t_1. Interference between the build-up of one signal

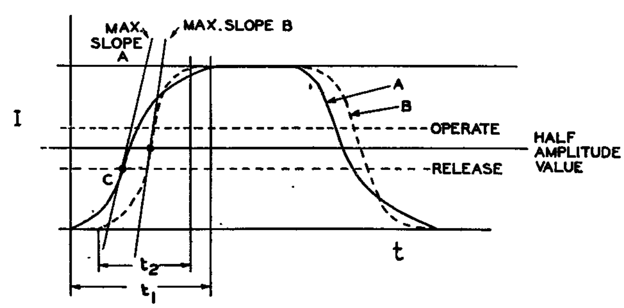


Fig. 13.—S.C.D.C. System. Improved Signal Waveform.

and the decay of the next arises, and distortion results, when the signal length is 0.4T or less; for example, on a line 100 miles 20 lb. 4-wire P.C.Q.T. $T = CRl^2 = 75$ mS and a signal of 30 mS suffers distortion. A terminating relay further degrades the signal slope. It is clear that the waveform B is better, as on the same line time constant the build-up time t_2 is less than t_1; it is symmetrical about the half amplitude value and its slope is greater at this point. This last point is of importance as with double current working the relay operates and releases at a point about the half amplitude value, and the more rapid the change of current in this region the less the distortion as the transit time is decreased and performance variation with permissible relay tolerances is minimised. The Single Commutation System incorporates a phase correction arrangement which enables waveform B to be approximately realised.

The principle of the phase correction arrangement is shown in Fig. **14**, where a line of time constant T is

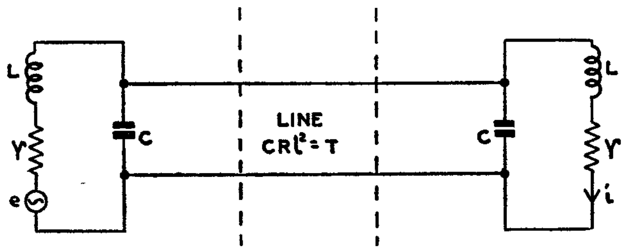


FIG. 14.—S.C.D.C. SYSTEM. IMPROVED WAVEFORM ARRANGEMENT.

terminated at each end by a damped parallel resonant circuit of $\omega_0 = \frac{1}{\sqrt{LC}} = \frac{K}{T}$ where K is a constant. It can be shown that with suitable choice of L and C the build-up of the current in the inductor can be made to approximate waveform B, Fig. **13**. In other words, the arrangement gives a phase characteristic which is almost linear over a wide range of frequencies. The termination gives an optimum performance at a specific time constant T fixed as the maximum line, but it will still give a substantial improvement in the waveform on lines of lesser T, the improvement decreasing with T. In practice the receiving end L and r are given by the receiving relay AP, and C by the bridge capacitor. At the sending end r (battery limiting and resistive relay windings) and C (bridge capacitor) are present and thus only L is required. This is given by the sending end inductor SC (Fig. **12**) and in magnitude is of the same order as the AP relay inductance.

(*b*) *Relay Transit Time Compensation.*

The AP relay transit time results in negative impulse distortion (loss of make) due to the conversion from double to single current working. The transit time is a function of the signal wavefront slope and may be regarded as a fixed mechanical time (which cannot be decreased by increase in slope) plus an incremental transit time which varies with signal level and slope. The incremental time may be compensated for in the relay itself by means of a biased third winding (Fig. **12**). A bias designed to compensate lines of maximum time constant will also give a measure of compensation at other line time constants. A relief high speed relay HSB compensates for the fixed mechanical transit time. The manually adjusted resistor VRB can be set to produce fast operation and slow release of HSB giving compensatory positive distortion and enabling contact HSB to repeat the impulses in substantially distortionless manner.

5.2.5.2. *Exchange Repetition Distortion.*

Impulse distortion is introduced by the line relay HS (Fig. **12**). Design of this relay is conditioned by the need to operate with:—

(*a*) Minimum distortion when preceded by an i/c S.C.D.C. relay set (*i.e.*, when forming a second link in a multi-link connection);

(*b*) Small distortion when preceded by a dialling-in junction of 1,200 ohms loop (see para. 5.1);

(*c*) Reasonable distortion when preceded by a subscriber's line, and at the same time to provide transmitter feeding current.

Condition (*a*) is made difficult by the action of condenser QB in slowing the decay of current in HS and is much worse if spark quench QG in a preceding i/c relay set is larger than 0.5 μF. Partial compensation is achieved by including the inductive windings of transformer i/c in the operating circuit of relay HS.

Conditions (*b*) and (*c*) result in positive distortion due to the action of the normal 2 μF spark quench.

The local repeating relay HSA converts from single to double current and introduces positive distortion due to the transit time and liability of its contacts to bounce. A compensatory negative distortion may be introduced into the HSA repetition by manually setting the resistor VRA.

5.2.5.3. *Limits.*

A feature of the manual distortion controls is that the overall distortion can be set, within certain limits, to any desired value irrespective of the line and local repeating relays. In practice both line and exchange components of distortion may be compensated and each may be set to zero with the aid of a suitable impulse distortion measuring bridge. When this has been done the overall distortion is nominally zero and with subsequent change in line length the change in distortion is found to be less than $\pm$ 1 mS. On a fixed line the only variation will be that due to variations of battery voltage and to change of relay adjustment.

As explained in para. 5.2.5.1. the limiting condition for satisfactory impulsing is set by the CRl^2 value of the line which should not exceed 75,000 μF ohms.

The limiting condition for signalling is set by the difference between the voltages of the batteries at two ends coupled with the effect of extraneous earth currents. With assumed values of 4 volts E.P.D. (although under magnetic storm conditions this may be greatly exceeded) and 3V A.C. (peak), and with adverse tolerances on exchange batteries of nominal 50 volts it is possible to meet a total loop resistance of 6,000 ohms, corresponding to 65 miles or 75,000 μF ohms of 10 lb. 4-wire P.C.Q.T.

6. VOICE FREQUENCY SIGNALLING — GENERAL CONSIDERATIONS.

Before dealing with various V.F. signalling techniques, it would be of interest to discuss a few of the main factors which have influence on the design of V.F. signalling systems, particularly signalling on speech path.

6.1. *Signalling Code.*

There are two main types (*a*) pulse and (*b*) continuous. Each has merit depending on the conditions of application and the number of signals to be given. For the purpose of discussion the pulse code of the present 2 V.F. system (Fig. **16**(*a*)) and the continuous code of the experimental Separate Signalling System (Fig. **16**(*b*)) will be treated as typical of their types.

6.1.1. *Pulse Code.*

It is B.P.O. practice to fit echo-suppressors on certain circuits and with the present 2 V.F. system, the condition shown in Fig. **15** arises. Energisation of

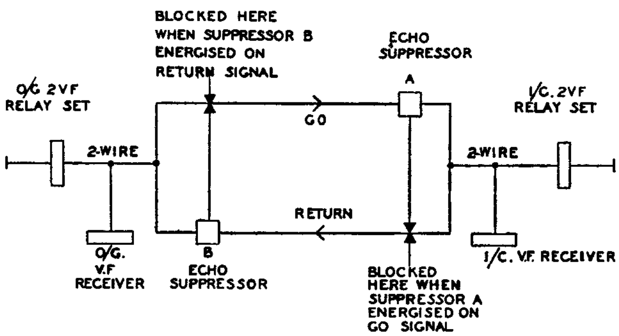
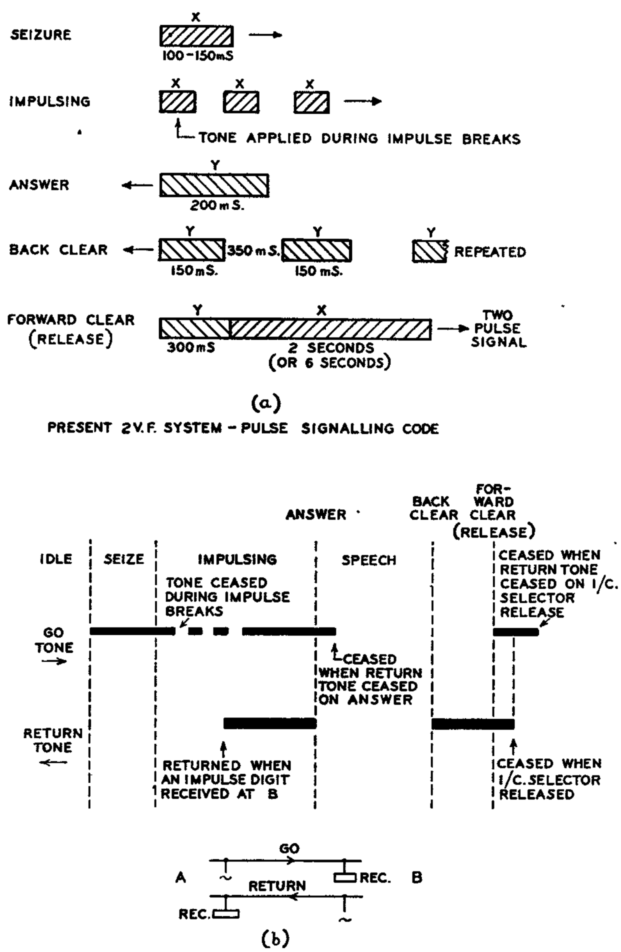


Fig. **15**.—Present 2 V.F. System. Echo Suppressor Condition.



SEPARATE SIGNALLING SYSTEM — CONTINUOUS SIGNALLING CODE

Fig. **16**.—Pulse and Continuous Signalling Codes.

suppressors due to a signal in one direction will block the return signal path and duplex signalling is not possible. Signals must be gapped to permit de-energisation of the suppressors and the transmission of signals in the opposite direction. Thus signal intelligence must be conveyed by pulses of signal frequency. Pulse signals result in system complexity as the pulses must be generated, and at the receiving end the pulse converted into " permanent " conditions by local circuits. Also the various pulses must be recognised by their duration, component (two frequencies or one) or sequence. On the other hand pulse codes permit a large number of signals to be given as obviously different pulses may be recognised by duration or component.

6.1.2. *Continuous Code.*

Simple circuit arrangements are possible with a signalling code more or less the equivalent of the D.C. case, as here the signals are " permanent " until the next signal condition occurs. Fig. **16**(*b*) will be discussed later in greater detail, but it is clear that such a code does not require local locking circuits and signals are recognised by the application or cessation of signal tone. On the other hand, however, the number of signals which may be given is limited by the application and cessation of tone.

6.2. End-to-End and Link-by-Link Signalling.

Two main methods of working are possible when tandem signalling.

6.2.1. *End-to-End Signalling.*

With this method, original V.F. signals on the first V.F. link (point A, Fig. **17**) are transmitted straight

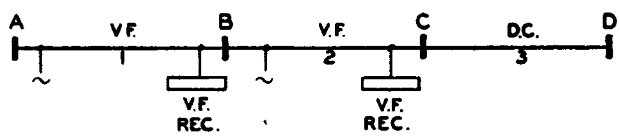


Fig. **17**.—Tandem Signalling.

through to the end of the last V.F. link (C) without repetition at tandem points (B). The V.F. tandem links are built up in sequence. Discriminating conditions are required to indicate whether a subsequent link is V.F. or D.C., and if D.C., the discrimination ensures that a V.F.—D.C. conversion takes place at the tandem point (C) so that D.C. signals may be transmitted over the D.C. link. This method allows wider signal distortion tolerances on the receiver as no distortion occurs at the V.F. tandem points ; the speed of signalling is increased as there are no conversion delays. On the other hand, the receiver must work to overall frequency and level ranges which could be the additive variations of the component links on a tandem set-up. With a large number of links the total ranges are liable to be wide, and this complicates the receiver design. A probability assumption of the variations would narrow the design limits.

6.2.2. *Link-by-Link Signalling.*

With this method each link is regarded as a separate entity. The V.F. signals are converted to D.C. at each tandem point, no discriminating conditions are required and the receiver is required to work to frequency and level ranges obtaining on one link only. This contributes to simple receiver design. On the other hand, as signal distortion is liable to occur at each tandem point, the receiver must give low distortion.

The link-by-link method is probably the more flexible in application as this would permit any possible new type of V.F. signalling system to be introduced into the network to interwork with existing systems without complications arising from various discriminating conditions.

6.3. Choice of Signalling Frequency.

Since the present 2 V.F. system was developed, further study on trunk line speech in regard to signal imitation by speech has furnished information which has influence on the design of any new signalling on speech path system. A signal imitation is said to occur when a frequency (or frequencies) in speech imitates the signalling frequency (or frequencies) for a certain time (delay time). For single frequency working it may be said that, in general, maximum imitation occurs in the region of 1000 c/s and an increase of signalling frequency above 1000 c/s reduces signal imitation, or alternatively, permits shorter delay times. A signalling frequency in the region 2000-2400 c/s appears to be a practical choice.

Compound signals, when two different frequencies are applied simultaneously, reduce signal imitation compared with single frequency and the higher the frequencies the less the imitation. All other factors equal, compound signalling permits shorter delay times and thus faster signalling.

The two-pulse signal, where a pulse of one frequency (or frequencies) is followed by a pulse of another, is another type and here again the higher the frequencies the less the imitation. Fig. **18** shows typical forms of V.F. signals. The signal is not completely effective until the total period $t_1 + t_2$ has been received. Sometimes t_1, the prefix, is utilised to condition the system for receipt of the suffix t_2 and to confine t_2 to a particular link, as otherwise its transmission over a subsequent link may cause difficulties. The times t_1 and t_2 are so chosen in each case to minimise signal imitation.

To summarise, the signal frequencies, or frequency, should be as high as possible and practical considerations set the limit. Two-frequency working is superior to single frequency in regard to signal imitation, but, and this will be discussed later, the choice between one or two frequencies is influenced perhaps more by the number of signals to be given rather than by signal imitation.

6.4. Receiver Guard.

To reduce signal imitation, receivers are designed to respond to frequencies lying within a narrow band centred on the signal frequency, and tend not to respond if some, or any, other frequencies occur at the same time as the signal frequency. The signal circuit thus tends to cause response and the guard circuit to prevent response of the receiver. There are many types of guard arrangements and Fig. **19** shows two typical examples. In (*a*) the guard circuit has equal

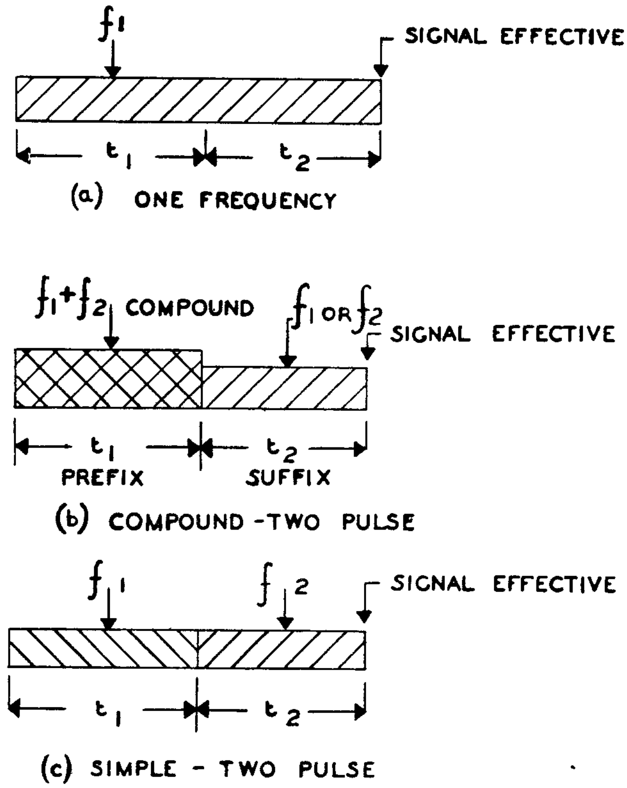


FIG. 18.—TYPICAL V.F. SIGNALS.

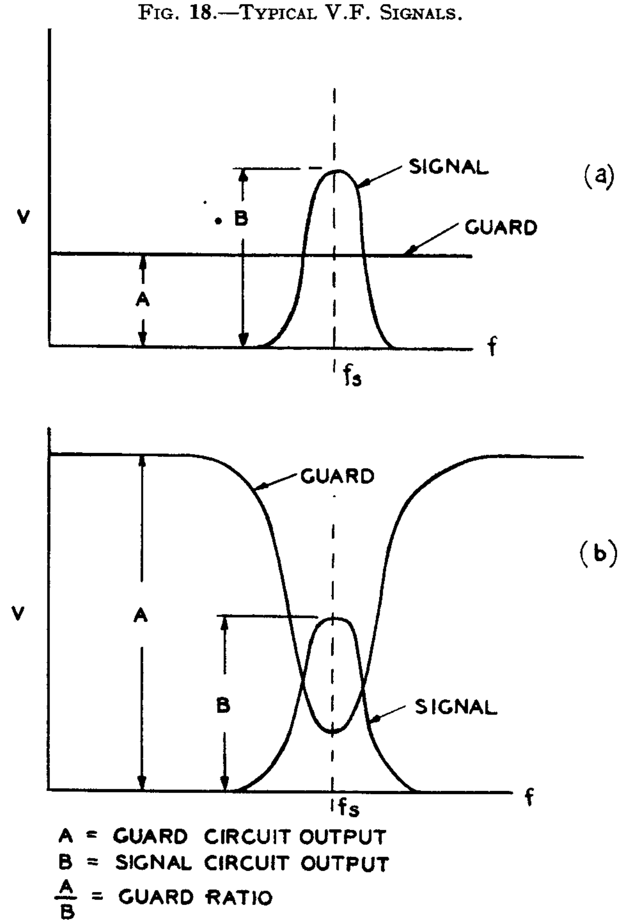


FIG. 19.—V.F. SIGNALLING. TYPICAL RECEIVER GUARD ARRANGEMENTS.

response over the whole frequency range, including the signal frequency, and in (*b*) the guard circuit output is reduced over a narrow band centred on the signal frequency. The receiver responds to the difference between the signal and guard circuit outputs, and for the purpose of this paper the relation between these circuits will be defined in a general way as $\frac{A}{B}$ which will be termed the guard ratio.

Tests have now indicated that signal imitation is greatly decreased as the guard ratio is increased. This applies particularly to guard arrangement (*b*) where the ratio can be greater than unity. Signal interference (when receiver response to a true signal is prevented or distorted by interference) limits the maximum sensitivity of the guard circuit. With high guard ratio and high signalling frequency there is little doubt that a tolerable signal imitation performance can be obtained with single frequency and practical delay times, and it may be reasoned that from the signal imitation aspect only, there is perhaps no compelling need to adopt two frequency as distinct from single frequency working.

6.5. Influence on Signalling Code of Number of Signals to be given.

It has been mentioned in section 6.3 that a two frequency system is superior to single frequency on signal imitation, but also in section 6.4 the case was discussed that with high receiver guard ratio and high signal frequency, a single frequency system could give tolerable signal imitation. The single frequency delay times will be longer than those of compound, but the difference is perhaps not sufficient to justify two frequency working for signal imitation performance alone. It may be reasoned, therefore, that the choice between single and two frequency working is influenced more by the number of signals to be given rather than by signal imitation. With single frequency working discrimination between signals can only be by pulse duration or sequence and if the number of signals is large the system tends to be complex due to the number of different pulse lengths required to be generated and recognised. Two frequency systems reduce timing complexities as the frequency component of the signal is available as a discrimination and from this point of view the system is simplified. On the other hand, additional equipment is required for the second frequency. There is little doubt that when a large number of facilities, and thus signals, are to be given a two frequency system is justified on the grounds of system simplicity, and as the two frequencies are available compound working is clearly advantageous. If few signals are required, and if these can be given without undue timing complexity, a single frequency system is worthy of consideration.

The same reasoning may be applied to the choice between pulse and continuous type signalling codes as a general case. Pulse codes permit a greater number of signals than continuous codes and thus the number of signals to be given will influence the choice.

6.6. 4-Wire Signalling.

British Post Office practice so far has been to connect V.F. receivers in bridge across the two-wire pair. In this position the receiver is subject to near-end as well as far-end speech and disturbances. This complicates the switching to the extent that repeated signals, or some such device, must be used to guard against the effect of near-end inputs. By locating the V.F. receiver and transmitting elements in the four-wire part (see Fig. **20**) simplification of the relay sets can be

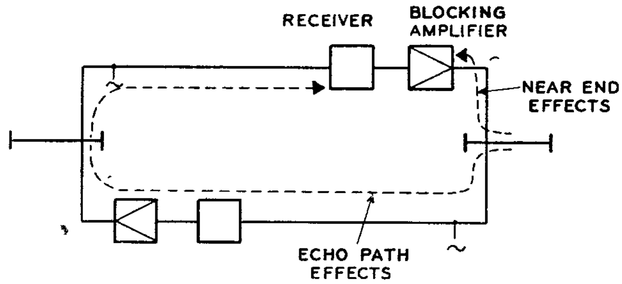


FIG. **20**.—V.F. SIGNALLING. 4-WIRE.

achieved. Near-end effects are required to be blocked to prevent interference to the receiver and the blocking arrangement may be an amplifier. The receiver is still subject to near-end speech round the echo path which is subject to severe attenuation distortion due to variation with frequency of the balance return loss at the terminating sets. In general the loss is least, and interference to the receiver greatest, at the two ends of the transmitted frequency range. Tests have shown, however, that unless the signalling frequencies are near the ends of the transmitted band the echo path effect is not a serious factor.

Assuming that echo-suppressors do not affect the signalling and that the channel is cut at the point where the signal is applied, connecting the receiver four-wire produces for the two directions of transmission, signalling circuits which are independent of one another and of any external influence while signalling is taking place. Clearly, therefore, four-wire signalling facilitates simplification of the signalling code.

7. V.F. SIGNALLING — TECHNIQUES.

7.1. Improved Signalling on Speech Path.

The limitations of the present 2 V.F. system were discussed in section 4.3. Possible methods to overcome the limitations will now be discussed. Seizure time may be considerably reduced by redesign of the relay sets, for example t_1 (Fig. **2**) could be reduced by transmitting the V.F. seizure pulse immediately on receipt of the D.C. seizure condition and t_2 by initiating selector seizure immediately on receipt of the V.F. pulse and not at the end. Alternatively the present seizure time could be tolerated by fitting outgoing regenerators with suitably controlled interdigital pauses.

Impulse distortion in the relay sets can be reduced by suitably designed high speed relay repetitions, or the difficulty overcome by the outgoing regenerator mentioned for seizure.

System complexity can be reduced by suitable choice of signal frequency (or frequencies) and signalling code. Elimination of the echo-suppressor effect on signalling and receivers located at the four-wire point contribute to system simplicity.

In regard to the dependence of speech on receipt of answer, it will be appreciated that an end of selection signal overcomes the difficulty, and with such a signal to set up speech conditions the stopper valve would not be necessary. An end of selection signal can be given by the restoration of the dial key on operator dialling and could be utilised on the operator's link, but as this signal is not passed by existing systems with which any new V.F. system would be required to interwork and would not be given on subscriber dialling, the dial key is not a general solution. Line split control by simple C relay control during dialling is not practicable as a split on receipt of the first impulse of a digit occurs too late to suppress the transmission of surges associated with the first impulse. Thus other solutions must be explored. Before proceeding, however, it would be opportune to discuss the delay guard as distinct from the receiver guard. This delay, to minimise signal imitation, is given by a slow relay and is switched in on the answer signal in the present 2 V.F. system. For obvious reasons this guard must not affect impulsing.

The dependence on the answer signal can be overcome, and the stopper valve eliminated, in a number of ways ; the following being typical methods:—

(*a*) Outgoing regenerator. Here the storage feature could be used to ensure that impulse transmission would not occur until the system had been conditioned as free from interference. Distinctive signals to switch the delay guard in and out could be transmitted under the control of the regenerator normal and off-normal conditions.

(*b*) Suppressing the signalling frequency from the speech path by a filter which could be switched out, and the delay guard switched in, on the answer signal. Prior to answer, speech and signalling can be regarded as separate paths and the delay guard would not be required until receipt of answer. Operator non-answer speech would be degraded by the filter, but this might be tolerable. Subscriber's speech, always under answer conditions, would not be degraded.

Delayed signal transmission appears a promising method of approach, but the regenerators are not always desirable. Suitable delays can, however, be obtained by other means. It will be recollected that the surges associated with impulsing are transmitted before the true V.F. signal (Fig. **4**). If time t could be such that the distant receiver, having responded to the surge, restores before the true impulse is received, then distortion due to surge interference would not arise. A feature in the outgoing relay set could be arranged to give the required delay, and with small receiver response and recovery times the delay time t could be small. It is essential that the delay feature itself should not introduce distortion and for this reason slow relay or capacitor charge and discharge delay features are not suitable, although a delay by static means is desirable.

A rectilinear D.C. signal applied to a low pass filter would give an output shown typically in Fig. **21**. A D.C. dialled impulse may be assumed to consist of a fundamental (nominal 10 c/s) plus harmonics and a low pass filter of prototype form shown can be designed to pass a certain number of the lower frequencies and at the same time introduce a delay.

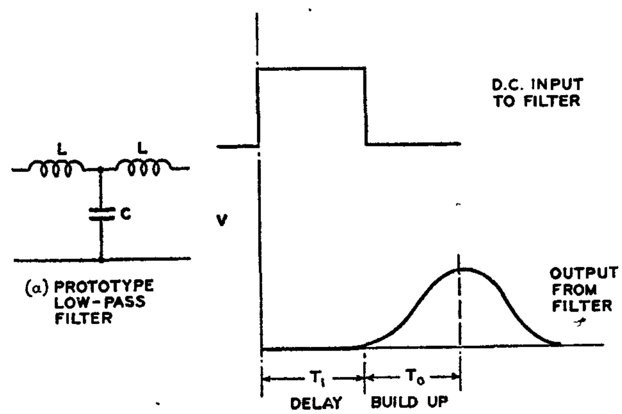


FIG. 21.—DELAY AND BUILD-UP OF D.C. IN A LOW-PASS FILTER.

Fig. **21** shows T_1 as the delay introduced and T_0 as the build up time of the signal through the filter. There is a relation between the build up time and the cut-off frequency and clearly, to avoid mutual interference between successive signals, the build up time should not exceed the minimum pulse time required, say 20 mS, and should preferably be less as rapid signal slopes reduce impulse distortion on repetition. With rapid receiver response and recovery times delays of the order 10—20 mS appear to be indicated, and these can be obtained with convenient components.

Fig. **22** shows a typical method of incorporating the

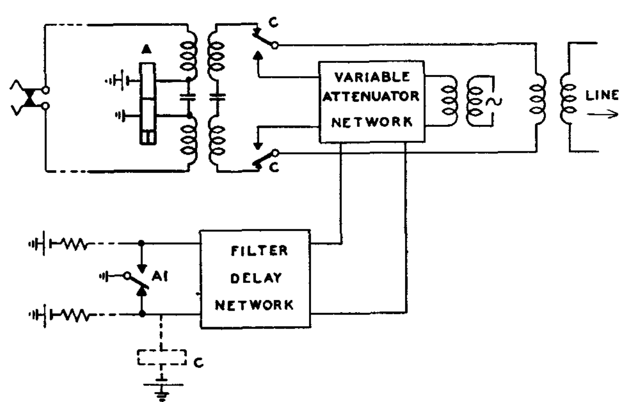


FIG. 22.—V.F. SIGNALLING. O/G RELAY SET DELAY ELEMENT.

delay feature in the system. Single Commutation D.C. signals are applied to the filter by contact A1, and the filter output, consisting of symmetrical signals suitably delayed, may be used to bias a variable attenuator network (*e.g.*, of the rectifier type) to key the signal frequency to line. The C contacts, operating on the first break of A1 and during the delay period, split the line to prevent interference. The circuit is restored to the speech condition at the end of each signal and dialled digit and the system is thus not dependent on an answer signal to perform this function. Surges associated with a first impulse of a digit will be transmitted to the distant receiver as the C relay line split will not be effective at this time, but the delay will ensure that the line surges have died out and the receiver recovered before the true V.F. impulse is received.

At the incoming end two problems arise. First, on tandem working, V.F. signals on a first link should not " spill over " to a second link sufficient to cause false operation. This is particularly important on link by link working. Second, the delay guard should be effective without dependence on an answer signal. It will be appreciated, however, that the guard may be present at all times providing it does not affect impulsing.

Assume a network interposed between the receiver and a relief relay P to give a symmetrical characteristic as shown in Fig. **23**. Relay P functions in double

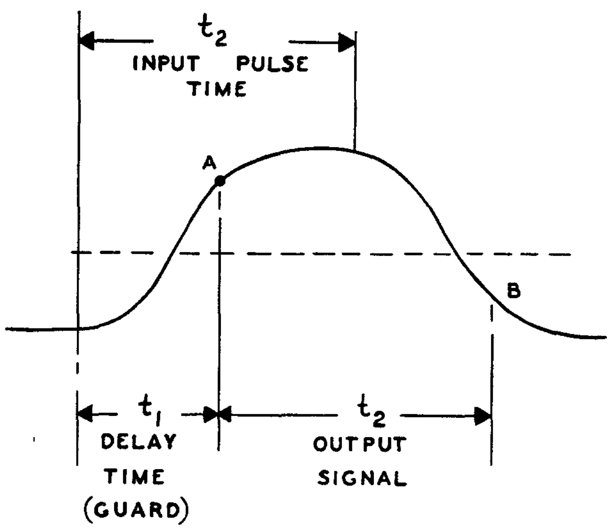


FIG. 23.—V.F. SIGNALLING. I/C RELAY SET DELAY.

current manner at points A and B equally disposed about the half amplitude value of the symmetrical signal. Operation at A initiates the receipt of the signal in the relay set. The line can be split within t_1 (and maintained split by other means) to terminate the spill-over. If the signal be an impulse, relay P reproduces the input pulse time t_2 in distortionless manner, but displaced in time t_1 from the input. Thus a signal is not effective unless it persists longer than t_1, which is a delay time and can be utilised as a guard. This guard, while present during, does not affect, impulsing, and is not dependent on receipt of answer. Energisation less than t_1 would be absorbed as relay P would not operate. Clearly with such an arrangement the delay time t_1 must not exceed the minimum pulse time of the system as steady state must be attained on the minimum pulse. In practice t_1 would be less than t_2 and would be less than, say 20 mS. Short delay times of this order would normally result in excessive signal imitations (and line splits), but as previously discussed the imitations can be reduced with high signalling frequency and receiver guard circuits of high sensitivity and rapid recovery.

7.2. Suppressed Frequency.

This technique purloins a band of frequencies for signalling from the band normally available for speech transmission. In other words, the signalling band is suppressed from speech and a separate signalling path over the voice channel itself is obtained. The typical case, Fig. **24**, shows the uppermost frequency band,

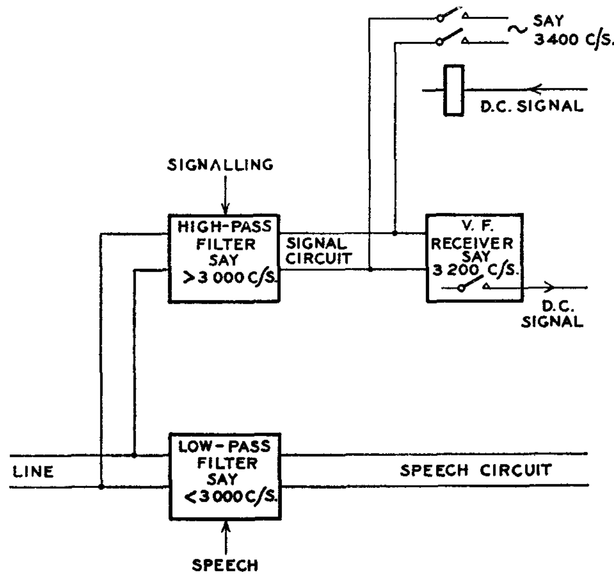


FIG. 24.—V.F. SIGNALLING. SUPPRESSED FREQUENCY SYSTEM.

on say a carrier system, utilised for signalling. The same principle applies to a signalling band more within the speech band, the respective filters being band stop and band pass.

An obvious objection is the transmission loss which is more serious if the signalling band is within the range 400—1600 c/s. To minimise the loss such systems should use mid-band signalling frequencies as far below 400 c/s or as far above 1600 c/s as possible. Clearly a limit may be set by the rising transmission loss of circuits in these frequency ranges. There are many circuits with a sufficiently low cut-off to force the signalling band more to the region of greatest transmission loss. For such reasons the technique was not proceeded with by the British Post Office.

The separate signalling channel within the exchange allows all the advantages of separate signalling working (simplicity, no signal imitation, no guards, etc.) which will be discussed later, without requiring a separate signalling circuit outside the exchange.

7.3. V.F. Signalling on Separate Path—Separate Signalling System.

This technique utilises a circuit, which could otherwise be used for speech, to serve the signalling requirements of a number of speech circuits. Unlike the suppressed frequency technique where the signalling circuit is separate within the exchange only, the signalling circuit is separate throughout and is associated with the relevant speech circuits by relay sets. The frequency spectrum of the signalling circuit is divided up into a number of bands (sub-channels), each of which, in the two directions, serves the signalling requirements for one speech circuit. The four-wire signalling circuit is kept open at each end (*i.e.*, is not brought down to two-wire). Echo-suppressors are not required.

7.3.1. *Advantages.*

As the signalling circuit is four-wire throughout and echo-suppressors are not fitted, there is complete freedom regarding the choice of signalling code which may be pulse or continuous, depending on the number of signals to be given. Signalling is conveniently duplex. The system, including the signalling code, is not complicated by safeguards against signal imitation. The problem of overcoming the dependence of speech conditions on receipt of an answer signal does not arise and the facility of continuous signalling permits rapid seizure by simple means.

All the above points contribute to the design of a simple signalling system.

7.3.2. *Disadvantages.*

The cost of the circuit appropriated for signalling must be included in the cost of the signalling system, and clearly to reduce the total cost the signalling equipment must be of simple nature and the signalling circuit should serve as many speech circuits as practicable.

Faults on the common signalling circuit may put all the speech circuits served out of service, and provision must be made to minimise this difficulty.

False set-ups may arise as it would be possible to set up a call on the signalling circuit with all lamp signals correctly given, and yet an associated speech circuit may be out of order.

End-to-end signalling, should this be desired, is not possible as this would require a particular signalling band on a first link to be connected to a similar band on subsequent links.

Fault tracing would be more difficult due to the more complicated nature of the set-ups.

Arrangements to avoid inter-channel interference tend to be complex particularly when the signal circuit serves a large number of speech circuits.

On routes with few speech circuits partially equipped signalling systems tend to be uneconomic.

7.3.3. *General Arrangements of the Experimental Equipment.*

The possible system simplicity appeared to be sufficiently encouraging to justify a measure of development and experimental work has proceeded on the general principles shown in Fig. **25**. The available frequency spectrum, assumed to be 300—2400 c/s, of independent Go and Return signal paths, is divided up into $n + 1$ bands (sub-channels). Each of the "n" sub-channels in the two directions serves one speech circuit, and the relay sets rigidly associate the speech and signalling circuits at each end as shown. The $(n + 1)$ sub-channel is used for alarming the condition of the signalling circuit and a continuous frequency is transmitted in each direction on this sub-channel. Mid-band signalling frequencies, generated by unit oscillators, are transmitted over the relevant sub-channels under the control of the relay sets. The

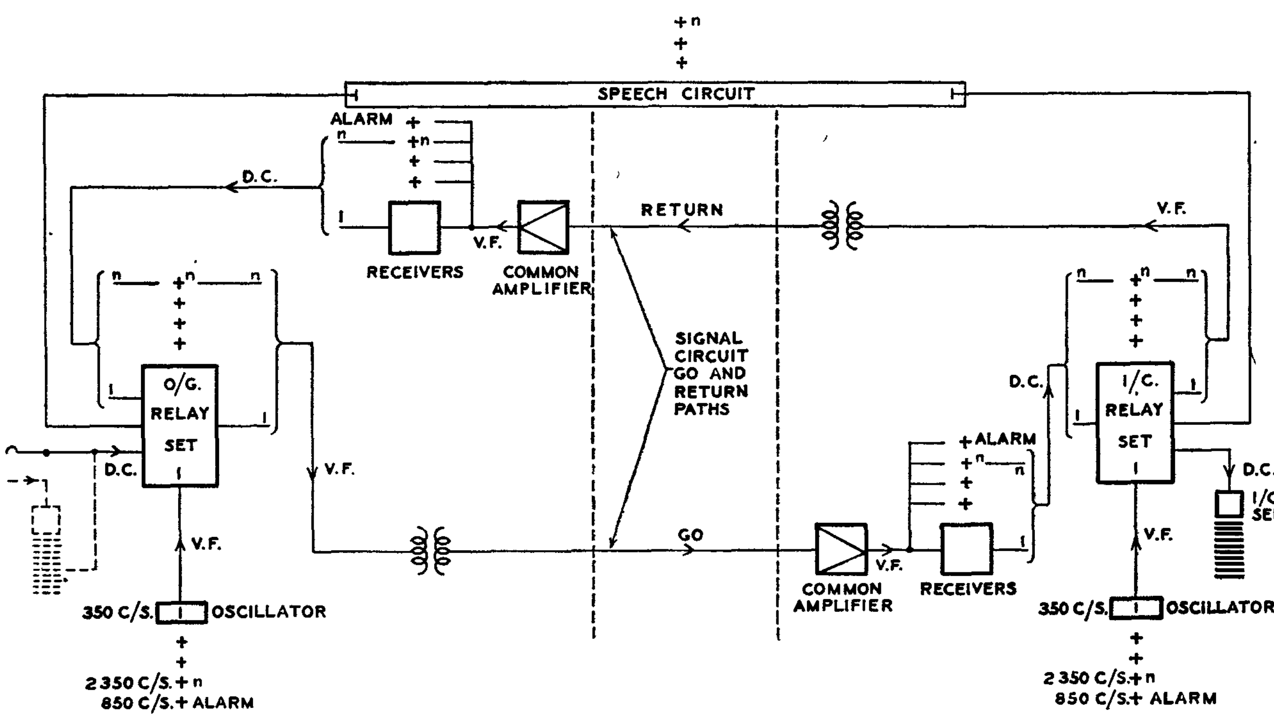


FIG. 25.—SEPARATE SIGNALLING SYSTEM. GENERAL ARRANGEMENTS.

oscillators at a particular exchange would serve the Go signal paths of outgoing circuits and the Return signal paths of incoming circuits.

For economic reasons each signal path has an amplifier common to all the receivers it serves instead of individual receiver amplification.

Frequency selective arrangements are incorporated in the receivers, and the D.C. output from each receiver controls the relevant relay set.

The facilities given by the experimental system are the same as those discussed previously for the Single Commutation D.C. System.

It will be seen that the basic arrangement of the system is much the same as that of the Multi-Channel V.F. Telegraph system.

7.3.4. *Design Features of the Experimental Equipment.*

7.3.4.1. *Signalling Code.*

The basic signals given on the national network are sufficiently few to permit a continuous code. A " tone on " during idle period code would give simplest relay sets, but this was not adopted due to (1) possible false seizures on fortuitous interruptions of the idle tone, (2) overloading of transmission amplifiers and (3) the simplest receiver design appeared to be realised with tone present immediately prior to impulsing, this being required for automatic bias for signal level. The direct alternative, the equivalent of the D.C. case, was not adopted because of transmission amplifier overload considerations as speech and signalling frequencies would be present at the same time on each sub-channel. For such reasons the code shown in Fig. **16**(*b*) was adopted. This is more or less the equivalent of the D.C. case except that the signalling frequency is ceased during speech. Semi-continuous is perhaps a more appropriate term for this code. It will be noted that the Return tone is not transmitted until an impulse digit has been received in the Go direction. This arrangement was adopted as otherwise a pulse of interference at the signal frequency would cause Return tone to be transmitted and this gave rise to clear down complications. Also it will be noted that while the Forward Clear Go tone initiates the release of the incoming equipment, the Return tone is not ceased until the incoming selector has completely released. The cessation of Return tone is used to cease the Forward Clear Go tone, and the release of the incoming equipment is thus line signalled to the outgoing end to free the outgoing equipment. This eliminates the more usual arbitrary slow relay guard, and possible unguard, at the outgoing end.

7.3.4.2. *Signalling Frequencies.*

The signalling circuit serves the signalling requirements of twenty speech circuits and, with the alarm frequency, the band 300—2400 c/s is divided into 21 bands of 100 c/s each. The usual technique of transmitting frequencies which are odd harmonics of a low fundamental, in this case 50 c/s, is employed. The lowest signal frequency is 350 c/s (transmitted in the band 300—400 c/s) and the highest 2350 c/s (in band 2300—2400 c/s).

Frequency generation is by oscillators, of conventional design, separate for each frequency, but each common to a number of systems.

7.3.4.3. *Signal Level.*

It was assessed that the signal level should not exceed -20 db. (ref. 1 mW. at zero level point) because of possible overloading of transmission amplifiers, and must not be less than -30 db. because of signal to noise requirements. The nominal transmitted level is -27.5 db. (this varies due to the pre-equalisation feature—see below) and the received level -19.5 db., as a nominal zero circuit is assumed to be $+8$ db. when without terminating sets.

7.3.4.4. *Level Variation.*

Variations are due, in the main, to (1) attenuation-distortion of the transmission channel and (2) variation in the nominal level of the signalling circuit. Of these (1), assumed for design purposes to be within $+2.5$ to -6.5 db. over the range 300—2400 c/s, is stable and known for a particular circuit, and in the system is compensated for by a manual pre-equalisation of the transmit level on the initial setting up of the signalling circuit. This simplifies the design of the common amplifier and receiver as the received level on each sub-channel is the same. (2), assumed to be $+2$ to -4 db. is taken up by an automatic bias in the receiver.

7.3.4.5. *Common Amplifier.*

With the signalling code adopted it is improbable that all 21 frequencies on a system will be transmitted simultaneously. Thus, instead of individual amplification per receiver, a common amplifier capable of dealing with eight simultaneous frequencies without overloading is used. Waveform distortion occurs with more than eight frequencies and this is of significance in regard to impulsing, which is a further probability. The amplifier, of conventional design, serves as a constant current (high impedance) source of power to the receivers which form the load.

7.3.4.6. *Alarm Frequency.*

An alarm frequency is transmitted and received continuously in each direction. This frequency serves to alarm drop in level of the signalling circuit and to initiate, at a pre-determined drop, automatic change-over to a reserve signal circuit. 850 c/s was selected as the alarm frequency as this is near the 800 c/s lining up frequency. A speech circuit is nominated as a reserve signalling circuit and on change-over, the main signalling circuit, considered faulty for signalling, is switched to speech to replace the reserve circuit switched to signalling.

7.3.4.7. *Receiver.*

The receivers of each terminal are connected in series and form the load of the common amplifier. They take the general form shown in Fig. **26**. After suitable filtration and rectification, single current signals are applied to the valve relay stage which incorporates an automatic bias arrangement.

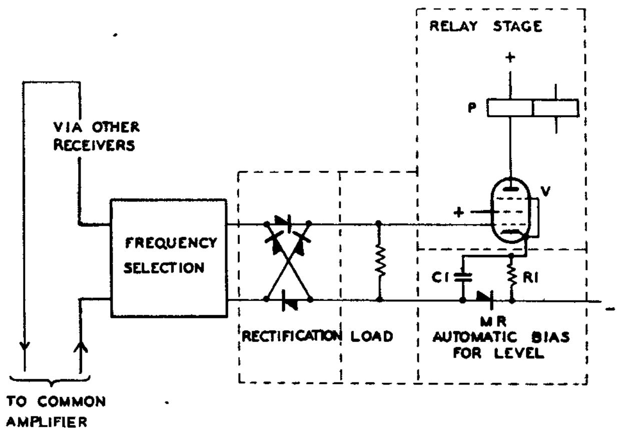


FIG. **26**.—SEPARATE SIGNALLING SYSTEM. RECEIVER ELEMENT.

In the experimental equipment, for economic reasons, the frequency selection takes the form of two shunt resonant circuits of same resonant frequency but different Q values. The respective outputs tend to become equal as the impressed frequency departs from resonance, and if a differential output be taken, this will tend to be zero for frequencies removed from resonance and have a value proportional to the difference in the Q values at and near resonance. Thus for given values of attenuation a differential scheme gives the effect of Q many times that of either of the constituent circuits. Alternatively, of course, the frequency selection may be band-pass filters.

To minimise distortion due to variation of received signal level the anode relay functions in a double current manner. Received level variation is mainly due to variation in the nominal T.E. of the signal circuit as variation due to attenuation distortion is taken up by the manual pre-equalisation. The receiver detects the half amplitude value $\frac{E}{2}$ (Fig. **27**(*a*)) of symmetrical single current signals and applies a corresponding bias to the valve. The relay operating at, or equally about, the half amplitude, reproduces the input pulse time T_2 regardless of signal level providing the signals attain steady state.

Fig. **27**(*b*) shows the automatic bias arrangement. In the normal condition a steady current flows through the valve due to the self bias on R_1. Application of input signal voltage variation will modulate this current. If the mutual resistance of the valve circuit be R, then the increment of voltage on R_1 due to a signal E volts will be $\left(\frac{R_1}{R_1 + R}\right)$. The rectifier MR conducts for an increase of voltage on R_1 and the capacitor C_1 charges rapidly to the increment. If $\frac{R_1}{R_1 + R}$ be 0.5, the voltage increment will be 0.5E which is the half amplitude value. When the signal E falls to zero the voltage on C_1 is substantially constant over a period due to the discharge circuit including the high back resistance of MR, and this voltage, acting as a bias on subsequent total changes of input E, causes the signal change of current to have positive and negative excursions about the steady current value.

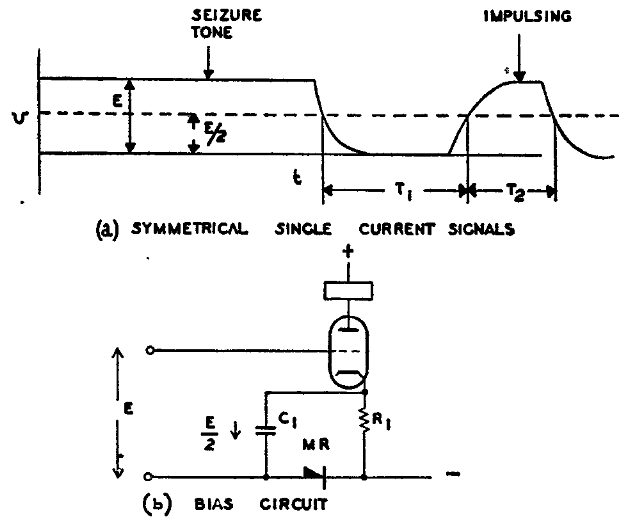


FIG. 27.—SEPARATE SIGNALLING SYSTEM. AUTOMATIC BIAS FOR VARYING SIGNAL LEVEL.

Since the bias is proportional to E, the fractional values of these excursions remain constant with signal level variation. C_1 is required to hold its charge substantially constant over the longest signal cessation period associated with impulsing (impulse break) nominal 66 mS which is a reasonable condition. With the signalling code adopted the half amplitude value is detected on the seizing signal tone and the correct bias is effective immediately impulsing commences. An alternative code with tone on during idle period gives an arbitrary and long signal cessation period prior to impulsing. A correct bias memory over such long periods is difficult to obtain and first impulse distortion is likely to arise.

7.3.4.8. *Transmitter.*

The V.F. signals are transmitted under the control of transmit relays with desired high impedance for signal ceased, and minimum impedance for signal applied conditions. The relays may be of the ordinary type, but preferably of the static type. Interference between sub-channels may be minimised by transmit band-pass filters. A basic conception of transmitting rectilinear signals by simple relay contacts and without transmit filters, is economically attractive, but is liable to set up sub-channel interference, and such a method requires careful assessment of the economic advantage against the impulse distortion which is likely to arise.

As mentioned, level variation due to attenuation frequency is pre-equalised at the transmit end by a manual setting. It was assumed that values +2.5 to −6.5 db. over the range 300—2400 c/s would meet almost all cases and the adjustment is made by a tap, in 0.5 db. steps, on a resistor across the transformer which feeds all the system frequencies to line. The alarm frequency (850 c/s) is connected to the tap corresponding to the nominal T.E. of the signal circuit and a transmit level −27.5 db. has been used. The arrangement (Fig. **28**) is such that frequency levels

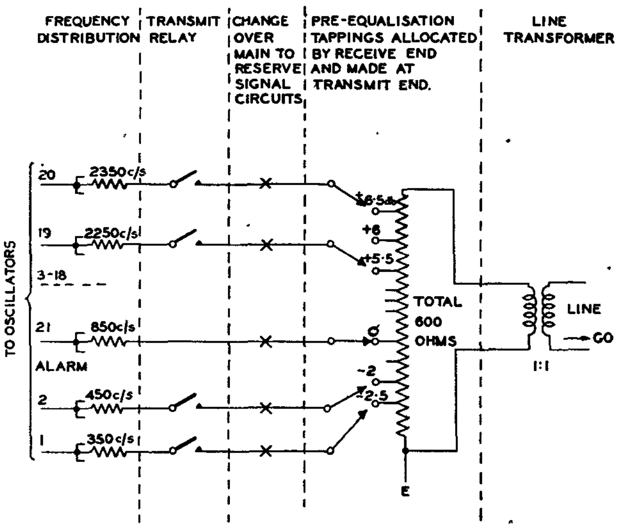


FIG. 28.—SEPARATE SIGNALLING SYSTEM. TRANSMITTING ARRANGEMENTS.

which would otherwise be received low, are raised at the transmitter (maximum level −21 db.) and lowered (minimum level −30 db.) if they would otherwise be received high. All the received frequencies are at equal level which corresponds to the alarm frequency received level −19.5 db. to within 0.5 db.

The transmitter arrangements are complicated by the need to pre-equalise both the main and reserve signal circuits because of the change-over feature.

8. CONCLUSION.

Past improvements in the field of loop-disconnect working have achieved a reduction in impulse distortion, but further improvements are required to raise signalling limits. A change from condenser to transformer type transmission bridges is favoured.

The Single Commutation D.C. system represents an appreciable improvement in the long distance D.C. field and will provide the means of dialling over four-wire amplified circuits.

In the V.F. field, signalling on speech path can be designed to meet all the requirements of the national network, and such systems have the merit that the signal path is available with speech. Signalling on a separate path permits fundamentally simpler signalling equipment than signalling on the speech path, but complexities arise when various safeguards such as alarms, change-over, etc., are required.

The multiplicity of D.C. and A.C. systems give rise to difficulty in concise descriptive titling and this will be evident from the paper. It has now been decided to adopt a numerical nomenclature, *e.g.*, the present 2 V.F. system will be known as A.C. No. 1.

The authors wish to thank their colleagues in the Telephone and Research Branches of the Engineer-in-Chief's Office for their useful suggestions on the preparation of this paper and in particular to Mr. T. H. Flowers for assistance and guidance on the problem of signal imitation and the V.F. signalling on speech path technique in general.

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