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Introduction.

The applications and advantages of voice-frequency signalling on long telephone circuits are well-known and require no further elaboration. This paper aims, firstly, at presenting V.F. signalling as a general problem, and, secondly, at describing the system which has been adopted by the British Post Office. A brief historical survey of A.C. signalling systems is included to broaden the outlook on the subject.

Historical.

The advantages of signalling with currents in the voice range were appreciated during the early stages in the development of long distance transmission over repeatered lines. The frequency of the signals being in the voice range necessitates some precautions being taken against speech currents actuating the signalling equipment, and V.F. signalling systems which have been devised are characterized largely by the methods employed to discriminate between signal and other currents. The fact that any particular frequency is not maintained in speech currents for any great length of time at once suggests that discrimination may be carried out by tuning the signal receiver to the signal frequency and delaying the response by a slow relay or other means. This method was the subject of a patent[3] filed in this Country in 1917. The delay required is, however, of the order of seconds. To reduce the delay, signals more complicated than a single frequency A.C. were devised to render them less liable to imitation by speech currents. In the United States of America several systems were developed in the period round about 1921 to 1925. One system[1], giving ringing facilities only, employed a signal composed of two different frequencies transmitted alternately, the signal being generated by an oscillator tuned first to one and then to the other frequency by a polarised relay vibrated by 16 c.p.s. ringing current. Another system[5] employed a single audio frequency interrupted by a relay vibrated by 16 c.p.s. ringing current. The 1000/20 and 500/20 ringing systems which later came into universal use also appeared during this period. A completely automatic operator dialling system[6] was also devised in which the supervisory signals consisted of a single frequency current interrupted at different rates for the different signals. In addition, a similar operator dialling system, but using multiple frequency unmodulated signals, was produced, protection from voice operation in this case depending upon voice currents never containing components at all the signalling frequencies simultaneously. Of these systems, apparently only 1000/20 and 500/20 survived. In Sweden[7] and Germany[7] systems were produced, about 1927, which employed single-frequency signals to operate signal receivers relying for voice protection on the fact that speech currents are always complex. The receivers for both systems are composed of two parts, a tuned detector responding to currents of the signal frequency and a guard circuit operated by currents of non-signal frequency. The guard circuit is operated by speech but not by signal currents, and when operated, it prevents any signal being given by the detector circuit. The receivers have been applied to ringing and dialling systems.

In England two systems[8, 9] were produced in the period 1928-30. One used multiple frequency signals to give full supervision, dialling and key-sending facilities. The other system used single frequency signals to give full supervision and dialling facilities, the signal receivers being protected against voice operation by a voltage, or current, limiter[10] in front of a tuned detector. The limiter was set so that the largest signal current that could pass it was just sufficient to operate the signalling equipment. Multiple frequency currents, such as speech currents, in passing through the limiter to the tuned detector had all their components reduced to something less than the maximum amplitude set by the limiter. In this way speech components at the signal frequency were reduced to below the level required to operate the signalling equipment. Another system[11], designed in England, and using a two-frequency signal to provide subscriber-to-subscriber dialling facilities, is in use on the Continent[12]. The British Post Office designed a system[13] in 1922 to give dialling and restricted supervisory facilities. The system described in this paper is one of a number which have been developed since 1929.

Operating Methods.

On short circuits where D.C. signalling is used, the signalling places little restraint on the operating procedure and it may well be argued that little improvement can be made on the methods which have come into universal use on such circuits. The operating conditions on trunk and local circuits are not the same in all respects, but the differences are not such as to make any radical changes in operating methods desirable for the longer circuits.

It is intended that, at the outset at least, calls set up over the trunk network shall be controlled by operators. To this end the V.F. signalling equipment has been designed to provide two sets of facilities, namely, manual-to-manual and manual-to-auto. by dialling, and each follows its D.C. counterpart as nearly as possible. The connexion shown in

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3. 1. 5. 6. See Bibliography.

7. 8. 9. 10. 11. 12. 13. See Bibliography.

Fig. 1 will be taken as an example to illustrate the two methods.

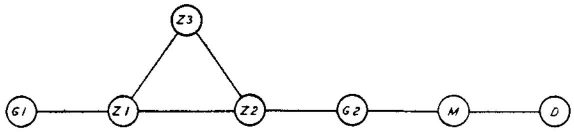


Fig. 1.—2-Frequency Signalling System. Method of Setting up Circuits. Explanatory Diagram.

The case shown is that of an operator at trunk exchange G1 wishing to set up a call to a subscriber on exchange D, the route being *via* zone centres Z1 and Z2, with Z3 as an alternative, group centre G2 and minor exchange M.

Manual-to-Manual.

If the trunk circuits are all manual-to-manual circuits, the operator at G1 selects a circuit to Z1. The action of plugging into the jack lights the calling lamp at Z1 where an operator answers the call, the supervisory lamp at G1 extinguishing when the operator at Z1 throws her speak key. The operator at Z1 extends the connexion to exchange Z2, where an operator again extends the connexion to G2. The operator at G2 calls the subscriber on exchange D by usual methods, either manual or automatic. The supervisory lamp at exchange G1 is extinguished by any one of the intermediate operators throwing the speak key or by the called subscriber answering, and is lit when the called subscriber has cleared and no intermediate operators are on the line. Normally all operators are off the line and the called subscriber controls a supervisory lamp at each of the manual exchanges. The D.C. signals from D to G2 have to be relayed at M because of the transmission bridges. The V.F. signals from G2 back to G1 would pass all the transmission bridges, but it is unfortunately not possible to avoid repetition of signals at each intermediate switching point. A V.F. repetition is of necessity slower than the corresponding D.C. action and this leads to slower signalling where several links are joined together. In the case illustrated, it would take some two seconds for the answering signal to reach the G1 exchange. The majority of calls, however, will require only one V.F. link on which the slower signalling is hardly noticeable, in fact flashing of the supervisory lamp at the standard rate of 0.75 second on and 0.75 second off is possible.

When clearing connexions, if one end of a circuit becomes free to be picked up for a further call before the other end has been cleared, confusion is likely to result. It is very desirable therefore that both incoming and outgoing equipments should test engaged until both ends of a circuit are unplugged. In any case since cord changing is a common operation on incoming positions, incoming equipments must not release on removal of the plug from the answering jack unless a clearing signal has been received. The backward clearing signal is no indication of whether or not the plug is still in the answering jack, making it necessary for the engaged condition at the incoming end of the circuit to be extended to the outgoing end by a distinctive signal. In the case illustrated in Fig. 1, the operator at G1 should be the first to take the connexion down, although the prior clearing by any other operator must of course be possible without causing trouble. The removal of the plug at G1 should light the supervisory lamp at Z1 and the circuit should still test engaged at G1 until the connexion is taken down at Z1. The clear from Z1 to Z2 should give the clearing signal at Z2 and the circuit should test engaged at Z1 until Z2 is cleared, and so on. It is apparent that if the forward clearing signal is one of two conditions determining the release of incoming equipments, forward clearing signals must be effective only on the circuits for which they are intended. In the case illustrated, for example, the clearing signal from G1 must be effective only at Z1 despite the fact that the first part at least of the signal may pass over the line to other exchanges.

Manual-to-Auto Dialling.

It is intended that ultimately all connexions will be set up by dialling, any trunk operator being able to call any subscriber in the country by this method. In the case illustrated in Fig. 1, the operator at G1 would select a free trunk from G1 to Z1 either from a multiple or by dialling if the multiple is dispensed with and all trunks are reached *via* selectors. The operator would then have to find from a card index the codes to be dialled to select trunks from Z1 to Z2, from Z2 to G2, from G2 to M, and from M to D. All the codes would of course appear under one entry in the card index. After dialling each code, the operator should listen for the audible signal—busy tone—that indicates that a line to the next exchange has not been obtained, as much time can be lost in dialling the complete digits when the call has failed through lack of outlets at an intermediate point. If, in the case illustrated, all trunks from exchanges Z1 and Z2 were found to be engaged, the operator would have to release the connexion and start again, this time to route the call *via* Z3 exchange. Having reached the terminal exchange D the numerical digits would have to be dialled to reach the wanted line. It will be observed that the setting up of calls over the trunk network by dialling may involve the transmission of impulses over a large number of circuits in tandem. Impulse distortion prohibits the repetition without regeneration of the impulses at each intermediate switching point, but unless the overall attenuation of a built-up connexion exceeds certain limits, there is no reason why signals should not be passed from end-to-end of the connexion without repetition at intermediate switching points. With end-to-end signalling, the number of impulse repetitions is reduced to one more than is required from the final group centre to the terminal exchange, and has other advantages particularly in clearing connexions, since all switches drop together. Impulse regeneration on the D.C. circuits outside the trunk network may be provided if required without affecting the V.F. signalling equipment. Regeneration of impulses, whether D.C. or V.F., within the trunk network can be provided if found to be necessary. Some use will also be made of translation facilities in large centres like London, to provide regeneration of the impulses and to relieve the operators of a certain amount of mental effort associated with dialling long codes. The only effect which translation has on the V.F. signalling equipment is in the provision of an audible signal to the operator to indicate when the storage and translation equipment is ready to receive impulses, and another audible signal to indicate when the translated digits have been pulsed out and further digits may be dialled.

Keysending.

Keysending requires considerable auxiliary apparatus, thereby substantially increasing the cost of the equipment, and shows a saving in operating costs only if the operators are allowed to do overlapping operations while the number selection is proceeding. The present policy of giving each call individual supervision up to the time of completion of the connexion thus prevents the advantages of keysending from being realized and it is not proposed to use this method of operating on trunk circuits.

Signals.

Signals consist of alternating current, within the voice range, of one or a number of frequencies modulated or unmodulated. They are distinguished from one another by their frequency, either of the A.C. or the modulation, by the sequence in which they occur, or by their time duration. Signals are frequently referred to as " tones."

The choice of signals to be used in a V.F. signalling system is governed by the following factors :—

(*a*) The functions to be performed by the system.
(*b*) The characteristics of the transmission system to be used.
(*c*) The characteristics of the V.F. signal receivers available.
(*d*) What may be termed the practical aspect of the problem, concerned chiefly with the reliability and cost of the equipment.

The functions performed by the system described later in the paper have been modelled on D.C. practice, but limitations in the transmission system and the apparatus available have prevented D.C. methods being exactly reproduced in the V.F. case. The transmission system available limits the frequencies which may be employed and the level at which they may be transmitted. Although sensitive relays have in the past been devised to work directly from the line current, it is now usual for thermionic valves to be used to amplify and detect the signals. Account also has to be taken of voice-switched devices in the transmission system—echo suppressors, for example, cause transmission to be possible in only one direction at a time. So far as the characteristics of V.F. signal receivers are concerned, a very large choice is available. Some are capable of detecting only one signal while others are able to detect a large number of signals. The degree of protection from voice-operation varies considerably, some additional protection in the shape of delayed response or signal sequence usually being required to obtain complete immunity from voice operation. So far as is known, all receivers are, or may be, adversely affected by speech and other currents occurring at the same time as signals, the method of guarding against speech operation always introducing this as a feature. Some receivers also exhibit the characteristic of taking time to recover from the effects of signal or non-signal input currents, that is to say, a certain time must elapse between the cessation of a particular input before the receiver is in a condition to receive a signal correctly.

The value of the line plant is high compared with that of the signalling equipment and costly signalling equipment can be justified if it results in the saving of line time. Reliability of the signalling equipment is, of course, of paramount importance.

Signal Functions required and Choice of Signals.

A signalling system giving the facilities enumerated in the section dealing with operating methods requires calling and clearing signals from the originating, or A, exchange to the called, or B, exchange, and answering and clearing signals in the reverse direction. In addition to these primary signals, dialling circuits have to provide V.F. dialling signals and manual-to-manual circuits have to provide flashing and extended engaged test facilities. Flashing signals enable either operator to recall the other : the extended engaged condition is the one already referred to, which prevents the A end of the circuit being taken for a new call before the connexion has been taken down at the B end.

A signal consisting of a tone applied continuously to the line to indicate one circuit condition and cut off to indicate another condition has some advantages, but it has the disadvantage on lines equipped with echo-suppressors that no other signal may be given in the reverse direction until the continuous tone has ceased. Signals are preferably, therefore, pulses of tone, that is, tone applied for short predetermined periods. Considering first a system in which all signals take the form of a single pulse of tone, the calling and clearing signals from A to B would each be a pulse of tone when the operator inserted and removed the plug from the multiple jack. The dialling impulses would be tone corresponding to the breaking of the dial contacts. The answering and clearing signals from B to A would be pulses of tone which alternately extinguished and lit the supervisory lamp. The pulse calling signal from A to B is quite satisfactory and in any case there does not seem to be any alternative. The dialling pulses have no disadvantage as signals and will not be considered further at this stage. The remaining signals have the disadvantage that they are liable to be lost by reason of disturbances occurring at the same time as the signals. The disturbances are speech or noise currents generated in the subscribers' and operators' transmitters and are impossible to avoid. They cause the loss of signals by operating voice-switched devices or by jamming the V.F. signal receivers. The loss of the clearing signal from A to B is particularly serious on a dialled call since it leaves the switches and the called subscriber held. It can be jammed only if the B end is uncleared, for if it is cleared no disturbance can arise. This being so, it can be arranged that when the clearing signal from B to A does occur—presuming that the subscriber or operator will eventually clear—the clearing signal from A to B is given again. This device is useful in the absence of anything better. The loss of one signal from B to A has the effect of reversing the supervisory lamp operation, the lamp lighting on answering signals and extinguishing on clearing signals, unless the two signals have some distinguishing feature, such as frequency or time duration. If the two signals are of different frequencies a suitable signal receiver can appreciate which is which. The appreciation of the signal on a time basis is conveniently accomplished only by slow-to-release relays and is not desirable unless the two lengths of signal are very different. If the signals themselves are generated by slow-to-release relays and the signal receiver sets an additional requirement in the form of a delayed response for speech protection, the timing becomes difficult.

Any system using as signals pulses of a definite length or number is open to the objection that signals are liable to be jammed at a voice switched device. Continuous pulses of tone to indicate a particular condition and cut-off to indicate another condition is a useful signal since, while difficult to jam, it permits signals to pass in the reverse direction during the intervals between the pulses. The limitation to this device is clearly that it cannot be employed from each end simultaneously. In a telephone V.F. signalling system the two signals most liable to jamming are the clearing signals from each end. Of these that from B to A is by far the more liable to jamming so long as clearing from A to B is dependent upon an operator. Choosing, then, as the clearing signal from B to A a continuous succession of pulses, the answering signal becomes the cessation of the pulses and the forward clearing signal a pulse long enough to break past a voice-switched device during an interval between pulses. This still leaves the possibility of the signal from A to B being lost due to jamming, a difficulty which may be overcome by repeating the signal when the called subscriber clears, as already described. Jamming by N.U. tone is a difficulty, the means of overcoming which is described later.

In the dialling case it is not possible to use the continuous pulses as the unanswered condition after dialling, as the transmission path is required for the transmission to the operator or subscriber of ringing and other supervisory tones. Once the subscriber has answered, the pulses may be used as a clearing signal. There does not seem to be any simple alternative to a pulse signal to indicate the first time the called subscriber answers. The pulse may be made free from the possibility of being jammed by having in the circuit a one-way valve repeater which will allow ringing tones to be heard, but will prevent any disturbances at the calling end from reaching the line. The one-way repeater has to be switched out before conversation can take place and the switching has to be done by the answering signal itself. Those circuits, *e.g.*, changed number interception, which do not provide an answering signal constitute a difficulty. A one-way repeater is, however, a useful device where a pulse answering signal has to be used, and has been adopted for the final scheme.

The preceding discussion is best summarized by stating what are considered to be the best signals for the essential facilities and which have been adopted for the final signalling system. It should be made clear that the decision was made after examining known systems, the signals not being novel to this system. The adopted signals are, from the outgoing or A end :—

(*a*) Calling signal—a short pulse of tone,
(*b*) Clearing signal—a long pulse of tone,
(*c*) Dialling—pulses of tone corresponding to the opening of the dial contacts;

from the incoming or B end :—

(*d*) Clearing signal—continuous pulses of tone,
(*e*) Answering signal—no tone, except that in the dialling case the first answering signal is a pulse of tone.

The signals not covered by the above are key flashing and extended engaged test on manually operated circuits. Flashing signals from either end are subject to jamming by disturbances generated in the subscribers' transmitters. The signals already decided upon for answering and clearing from B to A are free from undesirable results produced by jamming and given alternately produce the necessary flashing of the supervisory lamp at A. It is necessary, therefore, merely to arrange for the ringing key to send alternate answer and clear signals when flashed. Forward flashing and clearing signals are both required to light the distant supervisory lamp, but they must be different signals because the forward clear is, and the flash is not, one of two conditions—the other being the removal of the plug—which determine the release of incoming equipments. The distinction between the two signals may be one of frequency or timing, or both frequency and timing. Distinction on a frequency basis has been chosen for the final scheme. The flashing signal is tone sent when the ringing key is thrown and cut-off when the key is restored, this being the simplest possible circuit arrangement. The clearing signal is composed of two tones as will be explained later. The extended engaged signal may be a pulse of tone when the plug is withdrawn from the answering jack. Since it is the last signal in the sequence it may also be a continuous tone applied on receipt of the forward calling signal and cut-off when the plug is removed. It may not be the normal clearing signal consisting of a continuous succession of pulses if this signal is required to indicate to the A end that the forward clearing signal has been ineffective at the B end. The continuous tone signal has been adopted on the grounds that it requires less circuit complication than a pulse of tone and allows the final clear to take place more quickly.

Suppression of Dialling Surges.

Dialling signals are free from speech or noise jamming troubles. The receiver may be subjected to a speech or noise input just prior to the receipt of the dialling pulses, but this should have no effect unless the recovery time of the V.F. receiver is unduly long. What may be troublesome when dialling are surges generated by the D.C. part of the impulsing becoming superimposed on the A.C. impulses, to the detriment of the impulse repetition. As already stated, all V.F. signal receivers are adversely affected by non-signal currents occurring simultaneously with, or immediately prior to, signal currents. The selector stepping is invariably accomplished by impulsing on the speaking wires, thus producing surges which are of necessity in the speech and signal path. These may be suppressed from the V.F. signal receiver without much difficulty, either by relay contacts, since the surge follows a relay operation, or by hybrid coils. At the outgoing end of the circuit, the dial contacts have to be in the line circuit, as the same cord circuit must be used for both V.F. and D.C. dialling. If a relay is used to convert the D.C. signals from the dial to A.C. signals for the line, the surges produced by the impulsing relay precede the movement of the relay, thus making it impossible for the surges to be kept off the trunk line by relay operations. The point may possibly be made clearer by an example. The usual conditions are that the D.C. to V.F. conversion is to be done by an A relay bridged across the speaking wires, and that no circuit means of determining when dialling is about to commence is available. The A relay is required to send tone when released by the dial, the V.F. dialling pulses thus corresponding but displaced in time with the breaks in the dial contact. The dial contacts opening for the first time in a train of impulses produce a surge, sufficient of which reaches the V.F. receiver at the incoming end to interfere with its operation by the V.F. signal which commences when the A relay releases. The release of the A relay may be utilized to operate a C relay, contacts of which may prevent further surges from reaching the trunk line, but suppression of the first surge is impossible by this means. Some solutions to this difficulty are :—

- (*a*) The use of the dial contacts themselves to control the V.F. tone, thus eliminating a D.C. to V.F. conversion.
- (*b*) To make the throwing of the dial key isolate the conversion relay from the line, restoring conditions on restoration of the key.
- (*c*) The provision in the automatic system of an end-of-selection signal to indicate when dialling is finished, so that through transmission may be established only when dialling is finished.
- (*d*) To modify the receiver circuit for impulsing, and restore to normal by the called subscriber answering signal.
- (*e*) The use of a one-way repeater at the point where the D.C. to V.F. conversion takes place.

Solution (*a*) is attractive because it eliminates the impulse distortion inevitably associated with a D.C. to V.F. conversion. Its chief drawback is the limitation which it imposes on the building up of circuits, since it eliminates the possibility of having a D.C. link in front of a V.F. link. This limitation even prohibits having the manual switchboard in a building more than a few hundred yards from the V.F. equipment. A further disadvantage of the method is that it prohibits the use of a one-way repeater for safeguarding the called subscriber answering signal.

Solution (*b*) has the same limitation as regards a D.C. link in front of the V.F. link, as solution (*a*).

With solution (*c*) the transmission line is broken at the point where the D.C. to V.F. conversion takes place. The end-of-selection signal is used to restore through transmission so that ringing and other supervisory tones may be heard before the called subscriber answers. The solution cannot be applied in this country because an end-of-selection signal is not provided by the automatic switching equipment, nor can it readily be added to the existing equipment.

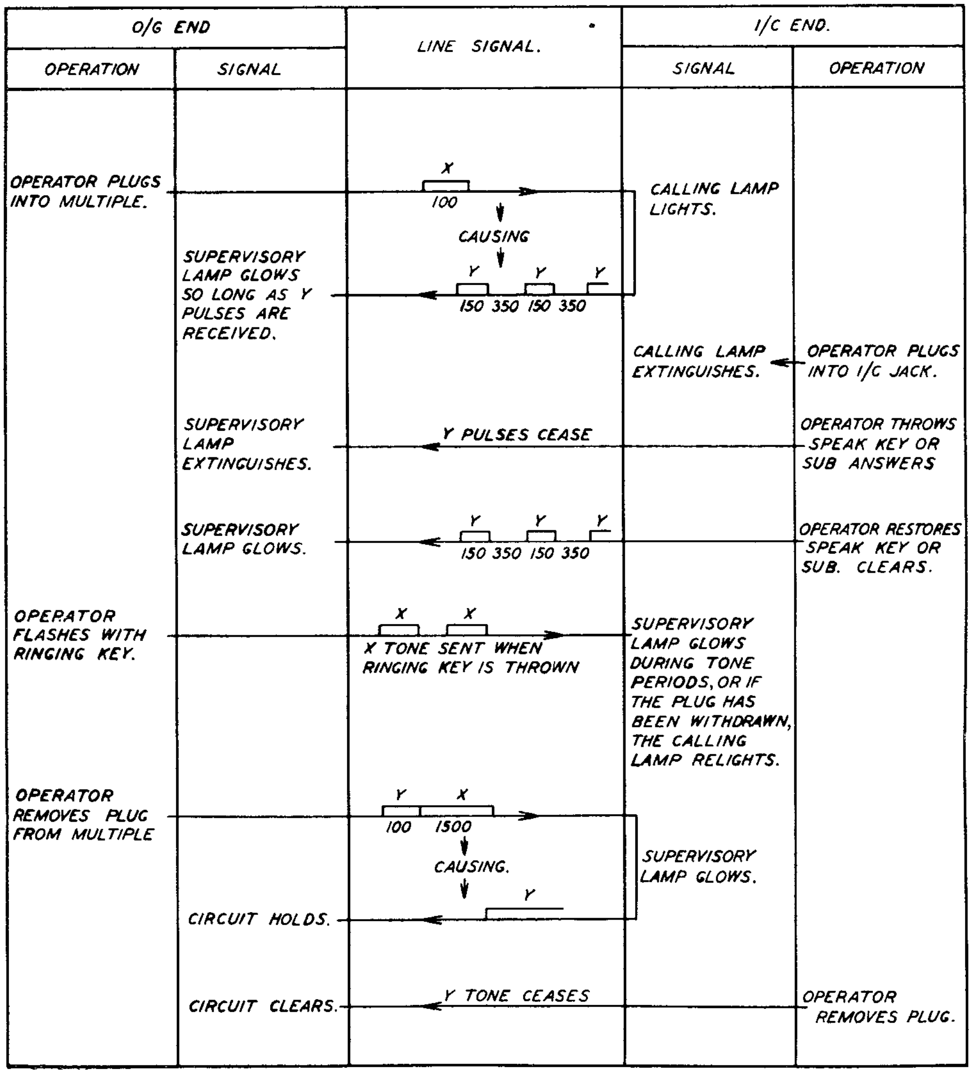
Case (*d*) is applicable only if the receiver is capable of modification to permit its responding to V.F. impulses accompanied by other currents, and if such modification still leaves the receiver immune from operation by ringing and other supervisory tones. It is a solution which is to be avoided if possible.

Solution (*e*) has been adopted for the British Post Office system. This device also prevents the loss of the answering signal, as has already been explained, and overcomes another difficulty which so far as is known cannot be overcome in any other way on automatic systems which do not provide an end-of-selection signal. This difficulty occurs if it is required to tandem three lines, the first and third being V.F., and the middle one D.C., dialling circuits. In this case V.F. dialling pulses from the first line are converted to D.C. for the second line and reconverted to V.F. for the third line. But without the one-way repeater device the V.F. pulses from the first circuit are able to reach and interfere with the V.F. pulses in the third circuit. D.C. dialling circuits within the trunk network are not likely to be common, but for flexibility in the system it is just as well to be able to use them if the occasion arises.

Number of Signalling Tones required.

So far signals have been referred to merely as tones. It is important to consider how many different tones are necessary or desirable since this clearly has a bearing on the signal receiver design. It is possible to do all the signalling with one tone, in fact, systems are in use in which only one tone is employed. The signals themselves are distinguished by their length or sequence and the direction of signalling by hybrid coils or other means. In the A to B direction the calling signal is distinguished from all other signals by its sequence, dialling and clearing signals by their lengths. In the reverse direction, answering and clearing signals are distinguished by their length, by sequence, or by the number of pulses comprising each signal. The V.F. receivers at each end of the line—and in the case of tandem connexions at each end of each line—have to appreciate the direction of some of the signals : for example, on a bothway circuit the calling signal has to produce a calling condition at one end of the circuit, but not at the end from which it was transmitted. The length of the signal is sufficient in some cases; or different tones may be used for the two directions of signalling, unless it is desired to limit the system to the use of only one tone. The appreciation of the direction of transmission other than by time or frequency is accomplished in a number of ways. For example, the relay contacts which connect tone to the line may at the same time disconnect the local receiver to prevent it responding to the signal. The same effect may be produced by connecting the signal receiver to the line by a hybrid coil which reduces the level of tone input to the local receiver to below the operating point of the receiver. Or again, a sent signal may be allowed to operate the local signal receiver and the effect of the receiver operation nullified by a relay operation associated with the sending of the signal. It is clear, however, that only the hybrid coil method of determining the direction of a signal is of any use at a tandem switching point. A hybrid coil is effective in this direction only if its balance is very good when signalling tone is transmitted at a fixed level, or if with a rough balance the sending level is adjusted to suit individual lines.

In the case of dialling circuits, no great difficulty is encountered in using one tone for all the signals. With the system of signals already described as having been adopted, the signals and their directions of transmission could, if required, be distinguished without much difficulty by their lengths. If, however, the facilities to be given by the system had to be extended at some future time, difficulty would almost certainly be encountered. The use of only one tone for manual-to-manual circuits causes a certain amount of difficulty in timing, unless the facilities given by the system are curtailed. For example, assuming that the receiver needs a delay in its response for speech protection purposes, the A to B flashing signal must have a minimum length greater than the delay time of the signal receiver,



NOTE:- THE ARROWS REPRESENT THE DIRECTIONS OF THE SIGNALS.
" LETTERS " " FREQUENCIES " " "
" FIGURES " " DURATIONS " " " IN MILLISECONDS.

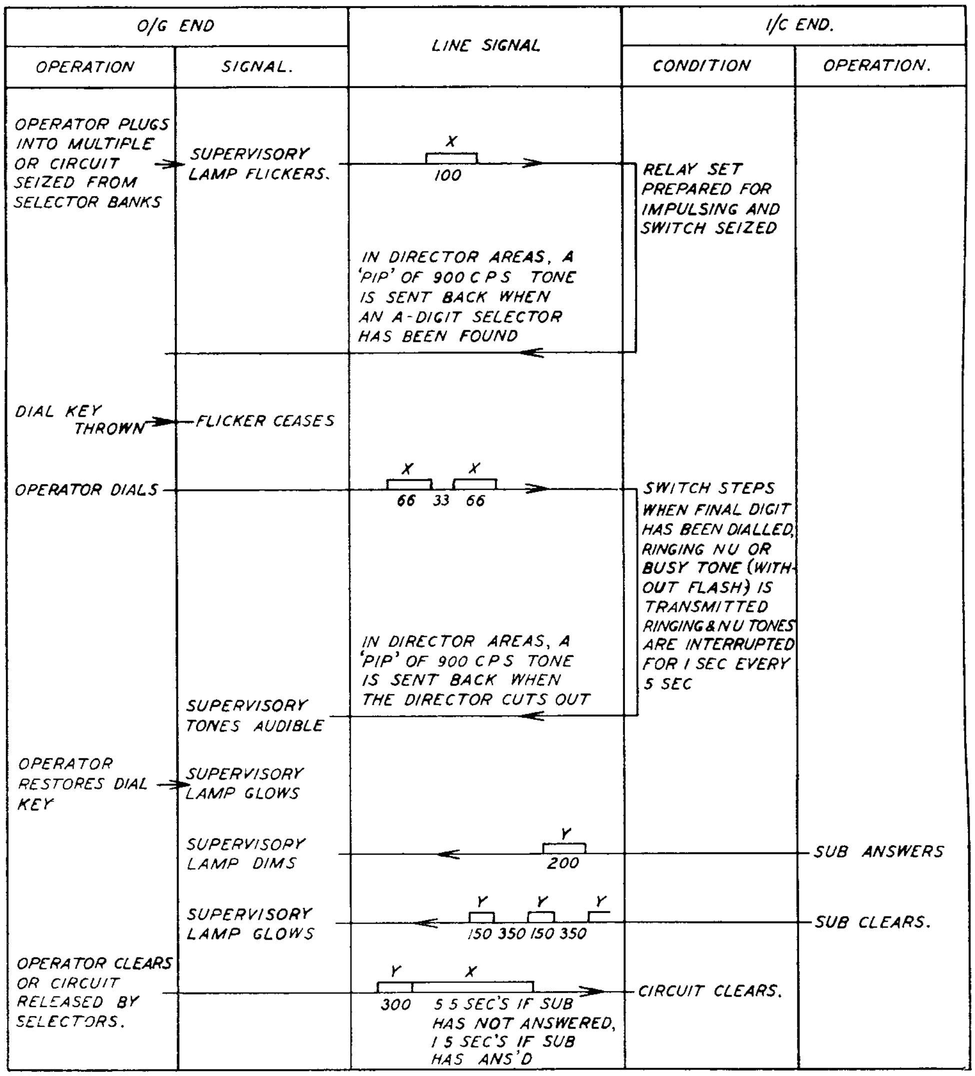
FIG. 2.—SIGNAL CODE FOR MANUAL-TO-MANUAL WORKING.

and the A to B clearing signal must have a minimum time greater than the maximum flashing signal. Slow-to-release relays are not easily maintained within the limits closer than about a two-to-one ratio between maximum and minimum release lags. If slow relays are used—and it is difficult to find any suitable substitute—to delay the response of the signal receiver, to time the duration of the flashing signal, to detect the flashing signal and to detect the clearing signal, it will be seen that the timing becomes difficult. It will be seen also that in the case of a tandem switching point, signals in the reverse direction may also add their lengths to the flashing signal unless hybrid coils are used to determine the direction of transmission.

If two tones are employed it is clear that a much greater choice of signals is available since in addition to varying lengths of the two tones, combinations of the two tones may be employed, *e.g.*, one followed by the other. It is clear, also, that a signal composed of a combination of two tones is far less liable to imitation by speech currents than one of a single tone and this may be used with advantage for the A to B clearing signal on which so much depends. With a larger choice of signals, difficulty in distinguishing signals by their lengths need not arise, with a consequent reduction in circuit complexity and increase in reliability; the possibility of providing further facilities is covered; and the necessity for hybrid coils, with their disadvantages, does not arise. For these reasons it was decided to adopt a two-tone system of signals which will now be described in detail.

Signals used in British Post Office System.

The two tones are each single frequency alternating currents and are called X and Y for convenience. The signals are shown diagrammatically in Figs. **2** and **3** for manual and dialling circuits respectively.



NOTE - THE ARROWS REPRESENT THE DIRECTIONS OF THE SIGNALS
" LETTERS " " FREQUENCIES " " "
" FIGURES " " DURATIONS " " " IN MILLISECONDS

FIG. 3.—SIGNAL CODE FOR MANUAL-TO-AUTO. WORKING.

Referring first to the manual case, the calling signal is a pulse of X tone of 100 m.secs. duration. The unanswered condition at the incoming end of the circuit is indicated by Y pulses of 150 m.secs. duration separated by intervals of 350 m.secs. The length of the intervals has been chosen to be long enough for existing echo suppressors to restore transmission to normal, it being assumed that all future voice-switched devices will also restore within the same time. The duration of each pulse has no particular significance; it is convenient from a circuit aspect and together with one interval makes up a round figure of 0.5 second. The answering condition is the cutting off of the pulses. Flashing signals are given by alternately applying the pulses to the line and cutting them off.

The clearing signal from A to B is a long pulse of X tone immediately followed by a short pulse of Y. The X pulse to be certain of being effective should be longer than any disturbance likely to occur when the clear is given. The longest disturbance is an indeterminate quantity : N.U. tone for example is of indefinite length. Busy tone and flash together may produce almost continuous disturbances and subscribers may talk for several seconds without pausing sufficiently long for the signal to become effective. It has been assumed that B operators will give a verbal notification of busy or N.U. tone or at least will not leave the circuits plugged up indefinitely. The duration of the X tone part of the clearing signal has been made 1.5 seconds as this time will outlast most of the ordinary disturbances, and should it not, the clearing signal is given again when the backward clearing signal (pulses of Y tone) is eventually given. There is thus no danger of permanent circuit lock-ups. The X pulse, when it becomes effective, lights the supervisory lamp. The Y pulse has the effect of making the glow permanent, that is, the lamp remains alight after the signal ceases. It also affects the circuit change necessary for the extended engaged test, the B-end then returning a continuous Y tone until the plug is taken out. Forward flashing is done by pulses of X tone timed by the ringing key operation and differs from the clearing signal by not having the terminating Y pulse. The distinction is thus one of frequency and not time. The two-frequency clearing signal has never been known to be imitated by speech and has the further advantage that given from A to B on a tandem connexion between A and C *via* B, the X tone part of the signal may be utilized to cut the line at B before the Y pulse occurs, thus confining the clear to its own link without the necessity for accurate relay timing.

In the dialling case, the calling signal is also a pulse of X tone of 100 m.secs. duration. The dialling pulses are X tones corresponding to the opening of the dial contacts. The clearing signal is X tone followed by Y tone. The X tone part of the signal should be long enough to outlast any disturbance on the line, as in the manual case, but here there is no operator to break down N.U. tone calls. The device has, therefore, been introduced of interrupting the N.U. tone on dialling circuits for a short period every so often, and making the X tone part of the clearing signal long enough to cover at least one break in the N.U. tone. The time between breaks has been fixed at four seconds, with 1 second breaks; more frequent interruption of the tone is liable to cause confusion between N.U. and other tones. The X pulse is made 5.5 seconds long to be sure of covering at least one break in the N.U. tone, but since this is unnecessarily long on a normal call, the receipt of the called subscriber answering signal is utilized to shorten it to 1.5 secs. as in the manual case. The terminating Y pulse performs the same functions as in the manual case. It is longer in the dialling case, but this fact is incidental to the circuit design and has no other significance. The called subscriber answering and clearing signals are the same as in the manual case, except that the first answering signal is a pulse of Y tone, protected against loss by jamming by a one-way repeater at the calling end. The pulse is preceded by a surge brought about by relay operations associated with the answering condition, for which reason it is made 200 m.secs. in length to give the receiver at the calling end ample time to recover from the effects of the surge before responding to the signal.

Choice of Signalling Frequencies.

The band of frequencies below 1000 c.p.s. was allotted for line signalling, that above 1000 c.p.s. being reserved for Telex and other purposes. A very satisfactory generator supplying frequencies of 500, 600, 750 and 900 c.p.s. being available, the choice of two of these frequencies became automatic. 500 c.p.s. is in use for 500/20 ringing and 900 c.p.s. was envisaged for trunk time announcing. The choice thus fell on 600 and 750 c.p.s., the 600 being the Y and the 750 c.p.s. being the X frequencies referred to in the foregoing.

Generation of Signal Lengths.

The signal lengths are generated by various means. The calling signals are timed chiefly by slow-to-release relays, as is also the first answering signal in the dialling circuits. The called subscriber clearing pulses are generated by a motor-driven impulse machine common to all the circuits at a switching centre. The clearing signals from the outgoing ends of the circuits are timed by uniselectors, of which there is one per circuit, driven by a half-second pulse common to the exchange, the two different lengths of signal used in the dialling circuit being obtained by stepping the uniselectors over different numbers of contacts round the arc. The flashing signals in the manual-to-manual circuits are timed by the operation of the flashing keys themselves.

Variation in Received End Level of Signalling Currents.

The received end level of the signals is subject to variation from a number of causes.

(*a*) The sending end level may vary ± 1 db. due to changes in generator voltage, variation in feed resistances and in the distribution leads.

(*b*) The transmission equivalents of lines vary with time. An allowance of + 1 to − 3 db. has been made for this cause.

Variations due to these two causes are unavoidable and must be allowed for in the design of the system. It is possible for the remaining causes of variation in received level to be eliminated, as far as the signal receivers are concerned, although to do so naturally places some restraint on the design of the system.

(c) The nominal T.E's of lines vary from line to line. With the improved transmission standards of trunk lines this variation is not severe, and should not exceed 0 to 3 db. on zone to zone, and zone to group, circuits. Adjustment of the sending level to suit the attenuation of the line is a device which may be employed if necessary. It is clear, however, that this method limits all signals to their own particular line and prohibits end-to-end signalling over a built-up or tandem connexion. In the case of manually operated circuits this limitation is not serious since the repetition of all signals at intermediate switching points is almost a necessity. In the dialling case, however, end-to-end signalling saves much time in receiving supervisory signals and saves repetition of dialling signals at intermediate switching centres. This last point is important.

(*d*) The terminal conditions affect the received tone level. In the extreme cases it is possible for the terminating impedance to be an open circuit, or a subscriber's line in parallel with an operator's telephone, causing the received level to be 6 db. above or 3 db. below its nominal value respectively. Under fault conditions the terminating impedance may be zero, special precautions being necessary in these cases to ensure that the signalling equipment is unaffected by the short-circuit. By the use of a hybrid coil to connect the V.F. signal receiver to the line, the input level to the receiver may be made independent of the line terminating impedance.

(*e*) The nominal transmission equivalents of lines exclude the losses due to terminal apparatus. This fact is unimportant except in the case of end-to-end signalling where the signals have to pass through the terminal equipments at intermediate switching points. 2 db. per switching point is a generous allowance to make.

Taking as the two extreme cases (*a*) one zero loss circuit and (*b*) two 3 db. and one zero db. circuit in tandem, the received end level of signals with constant nominal sending level may vary from + 2 to − 20 db. with respect to the nominal sending end level, excluding the variation due to the terminating impedance. These limits cover dialling impulses, the terminal conditions always being under control when impulsing. Supervisory signals may be 3 db. below to 6 db. above these limits, depending upon the termination, giving limits of + 8 to − 23 db. with respect to the sending level. The V.F. signal receivers designed for the Post Office system are able to cover these limits. It has thus been possible to design the system on the basis of end-to-end signalling on built-up connexions with considerable advantage both as regards design of the relay sets and operation of the system.

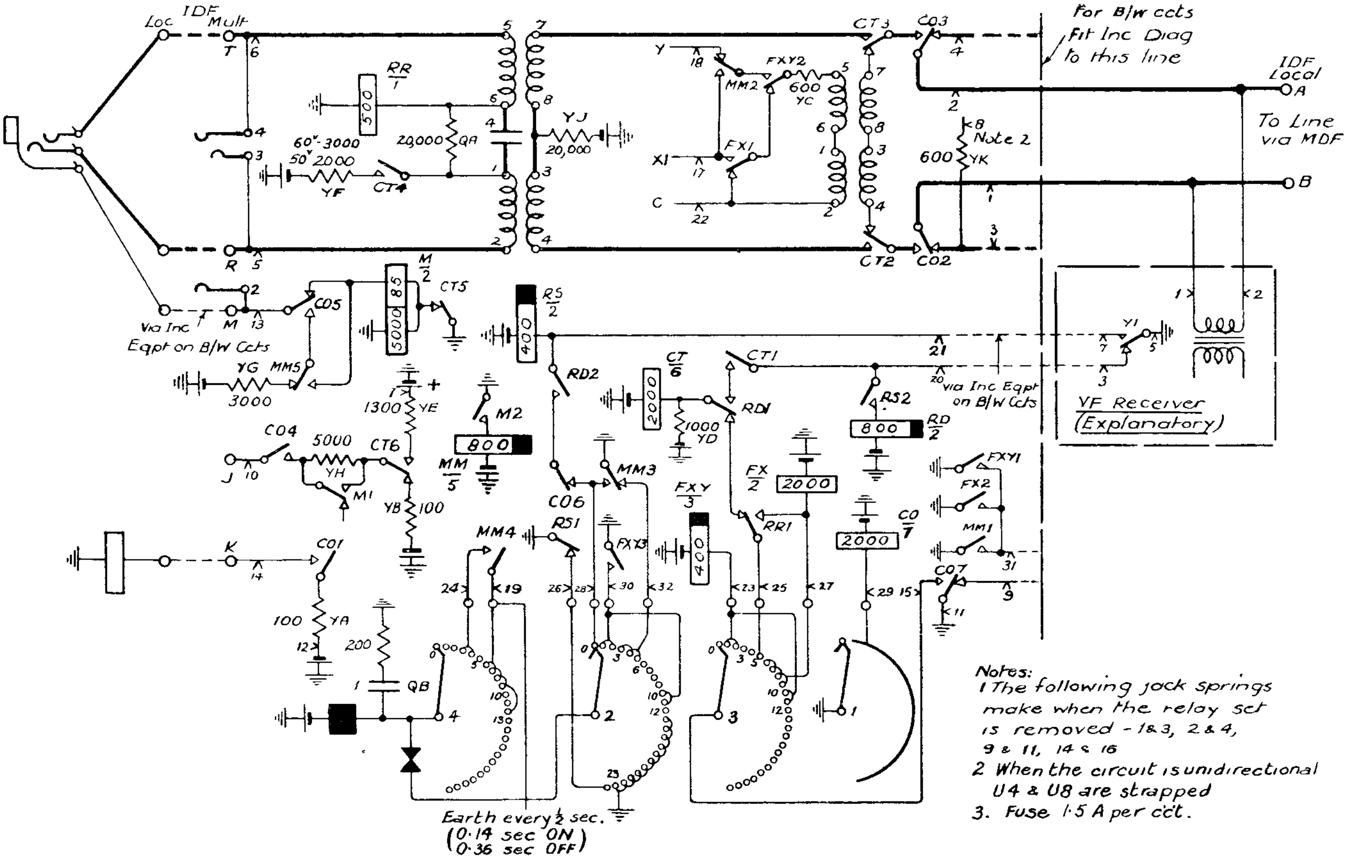
Circuit Details.

The equipment is made in five jack-in type units, viz., V.F. signal receiver, outgoing and incoming manual relay sets, and outgoing and incoming dialling relay sets. With these units, circuits may be built-up for unidirectional or bothway manual working, unidirectional or bothway dialling working, or bothway working with manual one-way and dialling the other.

The manual-to-manual circuits, which are shown in Figs. **4** and **5**, are comparatively simple and may be readily followed if the dialling circuit is understood. Circuit description will therefore be limited to the dialling circuits, and to salient points only. Figs. **6** and **7** show the outgoing and incoming dialling circuits respectively.

Referring to Fig. **6** it will be seen that the outgoing relay set is accessible from the manual board and from selector levels. Seized from the manual board, the control of the circuit is by the sleeve relay M, dialling pulses being sent by relay AM when impulsed by the dial in the cord circuit. The circuit may be seized *via* the selector levels by an incoming D.C. or V.F. signalling circuit. In the first case relay A operates, holds the circuit in the usual way, and performs the D.C. to V.F. conversion of the dialling pulses. If the preceding link is a V.F. trunk, relay AC operates instead of A, and all signals pass straight through the equipment, none being given at the intermediate point. The determination of whether the previous link is a V.F. or D.C. signalling circuit is performed while the calling signal is being sent out. At the instant of switching on to the relay set, the negative and positive lines are both joined to relay AC, *via* the A relay windings, one side of the relay AC coil being joined to battery. If the previous link is a D.C. signalling circuit, the negative and positive lines will be looped outside the relay set and relay AC will not operate, but if the previous link is a V.F. signalling trunk, earth will be found on both the line wires. Relay AC will then operate, the A relay showing no tendency to operate because the currents in the two windings oppose. If relay AC has not operated by the time the calling signal has gone out, relay FC operates to disconnect it and connect relay A in a circuit over which it can operate to a loop on the line wires.

By whatever method the relay set is seized, the calling signal is generated by the interaction of relay FXY with the uniselector, which acts as a sequence switch. The circuit then performs in one of two ways depending upon whether it has been seized (*a*) from the manual board or by a D.C. link *via* the selector multiple (*b*) by a V.F. link *via* the selector multiple. Considering case (*a*) first, the circuit is ready for dialling pulses when the calling signal has gone out, the one-way repeater being in circuit to stop surges reaching the line. It will be observed that the repeater has in its grid circuit a winding on the tone transformer, and in its anode circuit a winding on the line transformer, the desired one-way



Notes:
1 The following jack springs make when the relay set is removed - 1&3, 2&4, 9&11, 14&16
2 When the circuit is unidirectional U4 & U8 are strapped
3. Fuse 1·5 A per cct.

FIG. 4.—SLEEVE CONTROL SYSTEM. OUTGOING CIRCUIT MANUAL-TO-MANUAL 2-FREQUENCY SIGNALLING.

transmission being thus achieved in a simple manner. When dialling is completed, supervisory tones should be heard, and the called subscriber answering signal obtained. The pulse of Y tone which indicates that the called subscriber has answered causes the operation of relay SA. Subsequent incoming clearing signals cause relays RS and RD to be operated and relay CT to be released to give the necessary supervisory signal. It will be observed that relay CT does not release until the second Y pulse in the clearing signal, to introduce extra protection against speech operation as referred to later. When the circuit is eventually cleared, the uniselector self-drives from contacts 6 to 7 to release any switches holding to the P-wire, then steps from contacts 7 to 19, sending frequency X to line by the re-operation of relay B. If relay SA has not operated, all the steps from 7 to 19 are made under the control of the externally generated half-second earth pulse. If relay SA has operated, the switch self-drives over the first eight of these contacts and steps the remainder at half-second intervals. In this manner, the length of the clearing signal is made dependent upon whether or not the called subscriber answering signal has been received. At contact 19, relay FXY is operated to generate the Y pulse terminating the clearing signal. The switch pauses on contact 24 until relay RS releases in order to give the distant end time to clear before the outgoing relay set may be taken for a further call.

If the relay set has been seized *via* the selector multiple by a V.F. signalling trunk, the calling signal goes out and then relay CT operates to connect the lines straight through. At the same time, the uniselector self-drives to the 20th contact, thus preventing the clearing signal from being given again when the relay set releases. The clearing signal comes in this case, of course, from the first V.F. link and produces simultaneous release at all switching points in the chain. The Y pulse terminating the clearing signal operates relay RS in each outgoing relay set; the uniselector moves to its home contact on the release of this relay, the release lag of which covers the release of the equipment at the other end of the circuit.

Should the backward clearing signal (pulses of Y tone) be received at any time that the outgoing relay set is in the released condition, circumstances which are produced by the loss of the forward clearing signal for example, the pulsing of the Y relay in the signal receiver causes first the operation of relay RS, then relay RD, then the stepping of the uniselector from its home position. The uniselector continues to step either by self-drive or under the control of the half-second earth pulse, sending out the clearing signal on its way round to its home position again.

When the incoming relay set, Fig. 7, receives a calling signal, relays L and LL are operated by the operation of the X relay in the signal receiver, and relays HS and AR operate when the X relay releases. The contact of the AR relay is in one of the speaking wires over which it controls the selector train; in

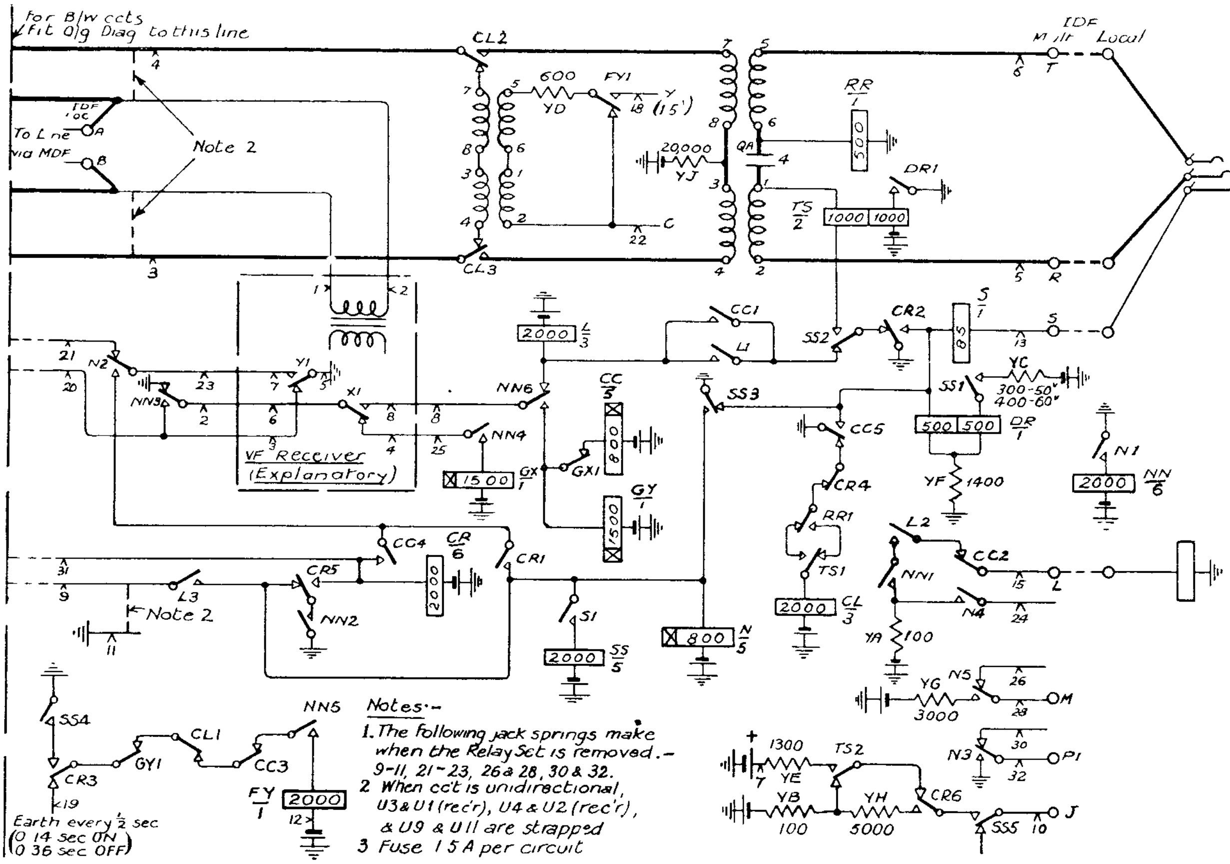
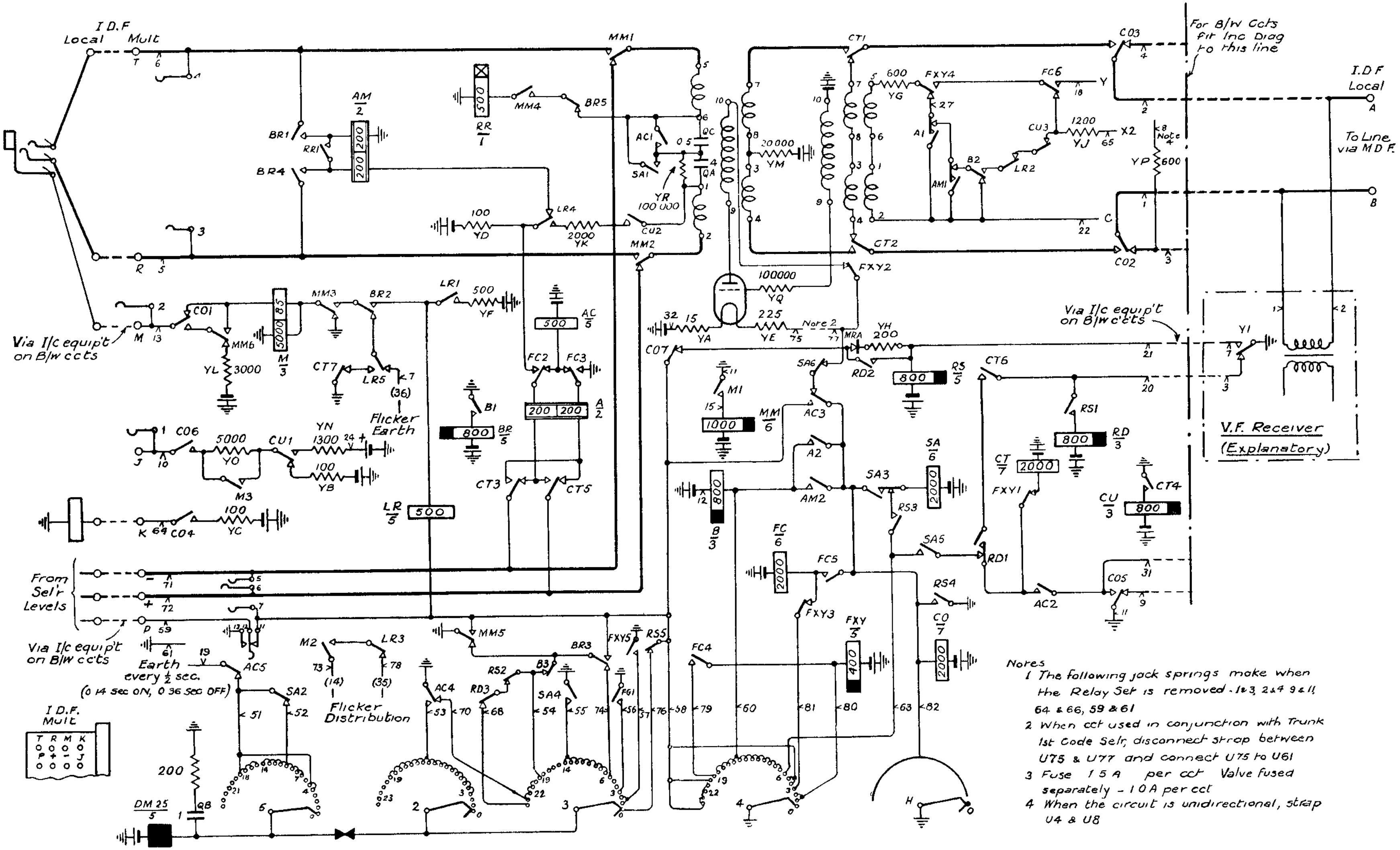


Fig. 5.—Signal Control System. Incoming Circuit, Manual-to-Manual 2-Frequency Signalling.

closing it sends a current surge into the V.F. receiver, for which reason its closing is delayed until the calling signal is complete. The selectors are impulsed by loop pulses but are held over one line by an earth through either the IL or the I relay for the reason which will appear later in describing the D.C. or V.F. line discrimination. The relays HS and AR are high-speed relays having operating and release lags of the order of one millisecond. The AR relay repeats impulses from the V.F. receiver to the selector, a high speed relay being used in order to keep the impulse distortion down to a very small value. Despite the short release time of relay AR, it is necessary to have a relay which will release even more quickly, to prevent the surge produced by the breaking of the AR1 contact from reaching the signal receiver. Relay HS is used for this purpose, series connected with the AR relay and with a condenser connected between them to produce the necessary difference in release lags. It is only at the beginning of the first impulse in a train that relay HS is required to stop the selector impulsing interfering with the trunk line impulses, the C relay performing this function during the remainder of the digit. The equipment will go on converting the V.F. trunk line signals to D.C. local signals unless relay I is operated as well as relay IL at the end of a digit. Relays I and IL are operated together by the battery, *via* relay AC, found on both line wires on switching to an outgoing V.F. signalling relay set. When this happens, no further signalling can take place, except for clearing the connexion. If the call is not extended by means of another V.F. signalling circuit, the selectors will continue to be held over one speaking wire. At the conclusion of dialling, supervisory tone should be transmitted back to the calling end, N.U. and ringing tones being chopped for 1 second every five seconds by the operation of relay CL by an externally generated pulse. When the called subscriber answers, the reversal of the lines which takes place causes relay I to be operated and relay IL to be released. The Y frequency pulse which indicates this condition to the calling end is generated by the release lag of relay PY, relay FY being operated during this period to connect the tone to the line. Speech may then take place. The clearing signal from the called subscriber causes relay IL to be operated again and relay I to be released, whereupon relay FY is impulsed by a half-second earth pulse generated outside the relay set. Any further answering signals have the effect of stopping the Y pulses. The called subscriber can flash the trunk operator's supervisory lamp by means of the Y pulses if the gravity switch is not moved too quickly.

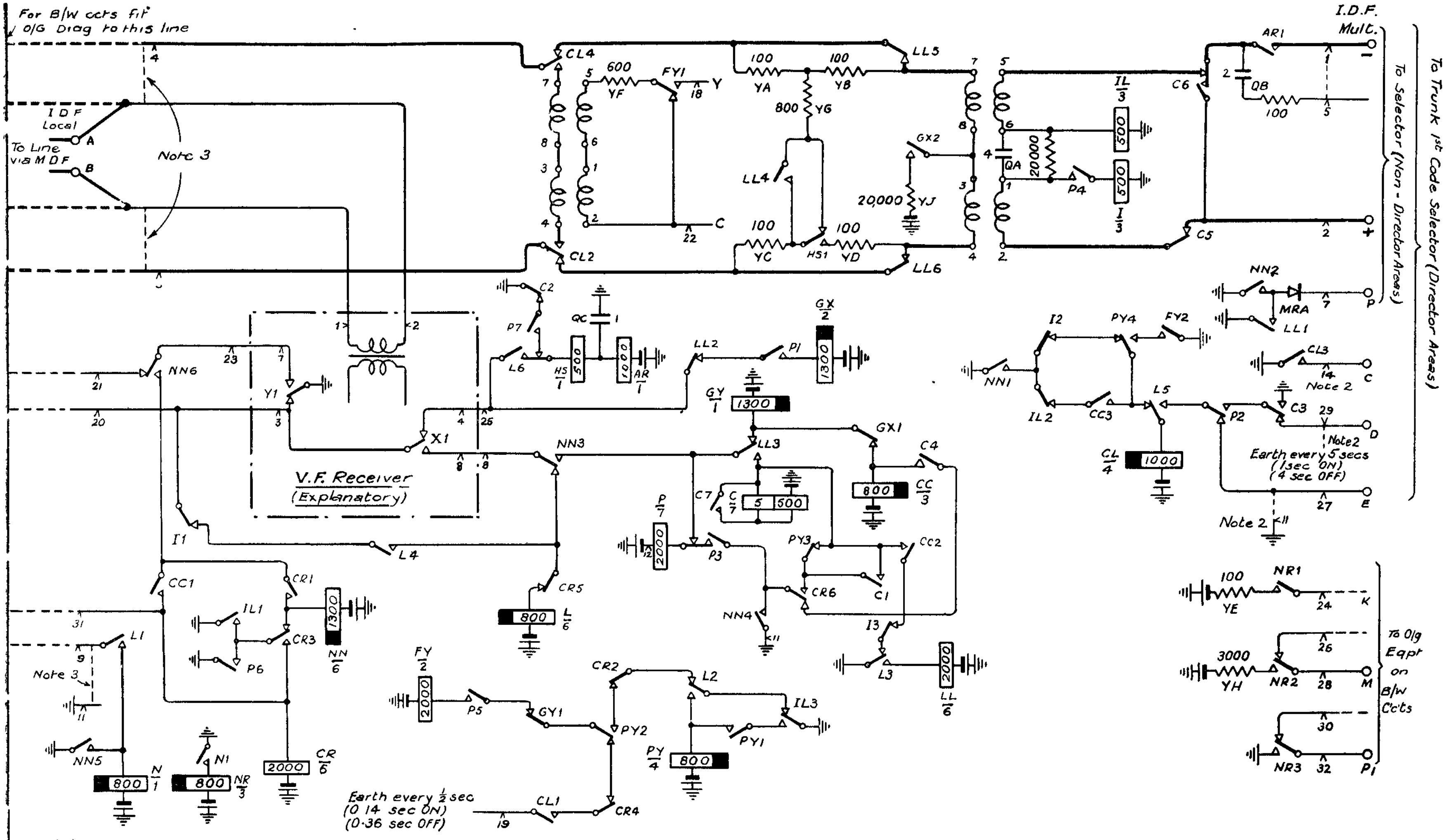
In the case of busy calls, the battery flashing signal on the positive line causes relay I to operate and release successively. This stops the one second every five second interruptions in the line, thus allowing the busy tone to pass unmutilated, but no other signal is given, the supervisory lamp at the originating exchange remaining bright.



Notes

1. The following jack springs make when the Relay Set is removed - 1 & 3, 2 & 4 9 & 11, 64 & 66, 59 & 61
2. When cct used in conjunction with Trunk 1st Code Selr, disconnect strap between U75 & U77 and connect U75 to U61
3. Fuse 1 5 A per cct Valve fused separately - 1 0 A per cct
4. When the circuit is unidirectional, strap U4 & U8

FIG. 6.—SLEEVE CONTROL SYSTEM. OUTGOING DIALLING TRUNK CIRCUIT TO AUTO. 2-FREQUENCY SIGNALLING.



Notes –

1. The following jack springs make when the Relay Set is removed :– 21 & 23, 26 & 28, 30 & 32
2. In Dir: Areas, U14, U27 & U29 wired to I D.F. In non-Dir Areas, U14 left dis, U11 & U27 strapped ; U29 connected to 5 sec earth.
3. When cct is unidirectional, U3 & U1 (recr); U4 & U2 (recr); and U9 & U11 are strapped.
4. Fuse 1·5A per circuit.

FIG. 7.—INCOMING DIALLING TRUNK CIRCUIT TO AUTO. 2-FREQUENCY SIGNALLING.

The connexion is cleared by a long X followed by a short Y pulse. The X pulse operates relay CC after a delay introduced by relay GX for speech protection purposes. The Y pulse operates relay CR, and the circuit releases when the Y pulse ceases. The circuit does not start to release until the clearing signal is complete in order that the release of the outgoing and incoming relay sets may take place simultaneously, and also in order that, in the case of through signalling on tandem calls, the clearing signal may be received unmutilated at all switching centres. It will be appreciated, that if the called subscriber clearing signal is being given when the forward clearing signal is applied to the line, there is the possibility of one of the Y pulses of which the former is composed adding itself to the X pulse of the forward clearing signal to clear the circuit prematurely. This possibility is prevented by operating relay GY by the X1 contact in its operated position.

It will be observed that an attenuator is associated with the line circuit. It performs two important functions at the beginning of each call. Firstly, it tends to stabilize the line terminating impedance while the selection proceeds. The impedance terminating the circuit at the beginning of the call is always high, being that of the selector A relay. Subsequently it may be anything down to roughly 600 ohms until the called subscriber answers. Secondly, under certain fault conditions it is possible for a selector to step on to a short-circuited line. In such circumstances it would be impossible to release the connexion were it not for the attenuator. The attenuator, which has a loss of 6 db., is switched out of circuit when not required, except for supervisory tones which must pass through it. The one-way repeater in the outgoing relay-set is in circuit for supervisory tones and is arranged to have a gain roughly the same as the loss in the attenuator so that supervisory tones do not suffer.

British Post Office 2-frequency Receiver-Operating Conditions and principles of design.

Design Data.

The evolution of a receiver, which would convert the A.C. tone pulses referred to previously into appropriate D.C. signals, has developed along the following lines, because the type and number of signals required by the circuit operating facilities of the system are not strictly comparable with those of past methods, so that the operating characteristics of the receiver must therefore be flexible.

The performance requirements are as follows :—

(*a*) The receiver must respond to A.C. tone signals of two frequencies, 600 and 750 cycles, independently, with the least possible delay, and will not be required to work on more than 1 frequency at a time.

(*b*) The received level may vary between wide limits for a sending level of 1 mW in 600 ohms (*i.e.,* zero level), the lowest level being about −20 db. and the upper limit +10 db.

(*c*) The frequencies may vary from time to time by a known amount of ± 0.3% due to the originating generator.

(*d*) The receiver must be practically immune from operation by trunk line speech, ringing, busy and N.U. tones and telex, without using long delay times in operating, since the whole system depends on transmission of tone pulses within time intervals much shorter than the delays normally used for this purpose.

(*e*) The bridging loss of the receiver must be small, a figure of 0.25 db. being estimated as the permissible maximum.

(*f*) The distortion, expressed as the difference between the time operation of the output D.C. contacts and the time of application of the signalling tone whether the latter occurs in an irregular or regular cyclic manner (*i.e.,* dialling), must be a minimum on at least one of the signalling frequencies. The X frequency, or 750 c.p.s. tone, is taken as the dialling frequency.

The above requirements are all well defined with the exception of the last one, which has been difficult to define owing to lack of information as to the overall distortion limits permissible in the V.F./D.C. conversion.

In the first place overall limits for the receiver—and these were to include all known and unknown sources of variation other than those given previously—of ± 3% on dialling at 67% make periods, were given; but it now seems that the distortions occurring in the D.C. portions of the contemplated through dialling routes, provide practically no allowances for the V.F. receiver, or alternatively, that reductions in such allowances, even of the order of 1% are of great importance.

In addition to the above requirements, the following are desirable :—

(*g*) Distortion by the transmission path of the received tone pulses must not affect the response of the receiver to any great extent.

(*h*) To the initial generator frequency variation must be added the effect of frequency variations due to a change in the transmission system (such as carrier working) and the initial mistuning of the receiver to within commercial production limits.

Since it has been contemplated that such a receiver would be mounted with the automatic apparatus in the exchanges it should conform to the following :—

(*i*) Preferably to work from the battery of 50 volts nominal, with possible extreme variations of 46 and 52 volts respectively, and with a minimum continuous load per receiver.

(*j*) The electro-mechanical design must be robust, and composed of components within wide commercial production limits, capable of being mounted as a whole on a normal jack-in type baseplate of the minimum size in order that accommodation problems can be met.

(*k*) The receiver must be capable of maintenance by the normal exchange staff, which implies that the initial adjustments must be simple and capable of giving a long continuous service without readjustment, under varying room conditions such as changes in ambient temperature, etc.

Principles of the Design.

From the foregoing summary of desirable features, it will be appreciated that the performance must be of laboratory sub-standard order, using commercial components and working conditions. Some experience prior to the design of this receiver was obtained with V.F. receivers for keysending and for the normal 500/20 signals, but neither of these receivers was expected to give results of such high precision as the present type.

The design work on the receiver has proceeded in two stages, according to the importance attached to the separate functions of the receiver. These are mainly, the function of being immune from operation by telephone trunk line speech, and the function of converting the signalling tone pulses into corresponding D.C. pulses. It was, and is, considered that the former should in no way interfere with the latter and *vice versa,* and that the removal of one of these features should not affect the functioning of the other. Since such a principle is somewhat new, it is obvious that primary consideration must be given to it.

Immunity of Operation on Speech and Non-signal Frequencies and Principles employed in Post Office Receiver.

As a first principle in securing immunity, the receiver is made to be more responsive to the signal frequencies by electrical tuning. The degree of sharpness of such tuning will depend on the permissible variation in performance over a band-width great enough to accommodate the variations in the accuracy of tuning of the receiver and in the signal frequencies. It may be taken therefore as axiomatic that such a simple receiver will be immune from operation by frequencies outside the operation band-width, unless these frequencies produce the signalling frequency by a non-linear action. Such non-linear action may produce the signalling frequency, in general, in the following ways :—

(*a*) Sub-multiples may produce a harmonic of the correct frequency.

(*b*) Multiples may produce a sub-harmonic of the correct frequency. Such production can occur in a telephone transmitter[15], but on a voltage basis appears to be not greater than 4% in the worst case (1500 c.p.s. producing 750 c.p.s.).

(*c*) Combinations of frequencies generally of a higher order may produce the correct frequency[15].

Since any non-linear action in the normal transmission path is far less than that necessarily introduced at the receiver, in compensating against variations in received signal level, and the device used is known to produce very strong simple harmonics, cases (*b*) and (*c*) are of less importance than case (*a*), and can be dealt with by the residual efforts of protection against the latter.

Therefore it becomes clear that it is only necessary to protect the receiver from the effects of these sub-multiples to render it reasonably immune from non-signal frequencies.

In the case of speech, a further distinguishing feature which might be used for protection against false operation is the unlikelihood of any particular frequency being maintained for a given length of time, when, if a delay greater than this is incorporated such operations can be prevented. In practice such a delay[1] is prohibitive. Another distinguishing feature may be said to be the variable amplitude of speech from moment to moment, and that consequently some amplitude constancy discriminating device could be used for the production of the true signal. But, if the receiver is to work without distortion on a single or repeated number of tone pulses, then the time delay in such a discriminating network would also be prohibitive, since some part of the signal must be used for the network to appreciate the fact that it has a constant amplitude. In addition, it is quite possible that after transmission over a long line the envelope of a tone pulse will no longer retain its constant amplitude feature.

Reverting to the case of sub-multiple protection, it is obvious that the fundamental sub-multiple frequencies themselves can be used to counteract the effects of their harmonics on the tuned receiver, and since they will be separated from the signal frequency by a ratio of at least 1 : 2 their effect on the true signal frequency will be small and can be neutralized, as will be shown later (see page 29). Again, if the signalling frequencies of 600 and 750 c.p.s. are considered it will be seen that their first sub-multiples are 300 and 375 c.p.s. which cover the range of fundamental speech frequencies generated by the average human larynx[15] and also the range of automatic tones in common use.

Principles employed in British Post Office Receiver in converting from Signalling or Dialling Tone Pulses to corresponding D.C. Pulses.

In the following, it will be assumed that the problem for both signalling and dialling will depend mainly on the dialling performance, since if the receiver will dial correctly then it will also signal correctly, provided due allowance is made for differing functions of the two signals.

Input Level Variation and Compensating Valve Stage.

Preceding the relay-operating valves it is considered that a further valve stage should be used, in order that the former may work under ideal conditions, whatever the input line level. This stage must provide compensation for such variations and is referred to as a limiter, or level compensating stage. The primary frequency selection as between X and Y frequencies will then take place between these two stages.

A more or less constant alternating voltage output

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[15] See Bibliography.

[1] [15] See Bibliography.

with varying input can be secured from a thermionic valve stage in a variety of ways, which resolve themselves, generally, into two main classes :—

1. Circuits employing a D.C. feed-back effect proportional to the output so that with increasing input the latter is made to work on a poorer amplifying portion of the valve characteristic, and if the latter is suitably designed in relation to the maximum input level, the output is reasonably undistorted. A common example is the A.V.C. system used in radio receivers.
2. Circuits employing a biassed shunting device which presents a large impedance to amplitudes not exceeding the bias in one direction and to any amplitude in the reverse direction, but whose impedance falls to a low value in the former direction when the bias amplitude is exceeded. If this impedance is sufficiently low in comparison with the supply impedance then the amplitude excursions in this direction are restricted by virtue of the power taken from the supply.

The objections to the use of either of these two types are firstly, that the output cannot be termed " constant." In case (1) the gain of the stage is merely reduced by a ratio depending on the ratio of control exerted by unit change in the output. The output will therefore increase with increasing input, but with much less rapidity. In case (2) the peak output increases because the shunting device invariably has a finite resistance when conducting, whose value varies with the current passed. In addition, the amplitude of the fundamental as selected by a tuned circuit, will increase with increasing input since the ratio of base line to peak amplitude increases for a given half cycle. Secondly, the output A.C. energy will not be the maximum possible, since in case (1) the valve characteristics will be inferior by virtue of incorporating a variable gain effect and in case (2) considerable losses occur since the function of such a circuit is to by-pass energy in increasing amounts as the input level is increased. This restriction of output energy is serious, since the battery voltage to be used is low.

The type of constant output device used is a development of the overload amplifier principle and avoids most of these objections when properly designed. It consists of an ordinary triode valve working initially with zero or positive grid bias, in the grid circuit of which is placed a high resistance shunted by a condenser, in series with the secondary of the input transformer. Since the resistance is high the working point on the grid volts/anode current or grid current characteristics, in the absence of A.C., occurs at the grid voltage at which grid current commences to flow. When A.C. is applied to the input of the transformer, grid current will flow on the positive grid swings and will cause a steady potential to be developed on the condenser in such a manner as to provide an additional negative bias almost equal to the peak value of the A.C. voltage on the secondary. (See Fig. **8**.)

When this additional bias due to an increasing input level reaches the steady value which would reduce the anode current to zero, then further increase in level will not materially affect the A.C. grid swing and therefore the A.C. anode current swing. Owing to the rapid change of slope of the grid current/grid volts curve the extra bias on the condenser is easily maintained with but a small increase in the positive grid swing. Theoretically this would mean that once past the grid bias to give zero anode current, the output A.C. swing would be unaltered with increase in applied level, and the fundamental output as selected by the tuned circuit, would gradually decrease from this maximum, owing to the decreasing ratio of base to amplitude of a half-cycle. Actually this drop in output can be nullified by inserting series resistance in the input or output of the transformer, making the positive peak applied to the grid progressively flatter as the level is raised. This feature, taken into conjunction with the steady but small increases in the excursion of the grid swings into the grid characteristic, enable an almost constant output to be maintained on a resonant circuit tuned to the fundamental. In practice such a stage will keep the fundamental voltage output constant to within ± 3% over a level range of 25 to 30 db.

In addition, the maximum possible A.C. output consistent with low tapping loss is being obtained since the effective grid swings are from the zero anode current bias to the initiation of grid current.

It will be appreciated from the above explanation that the performance of such a stage depends on two factors, firstly, the grid swing from cut-off anode current to initiation of grid current and, secondly, the corresponding change in anode current. The

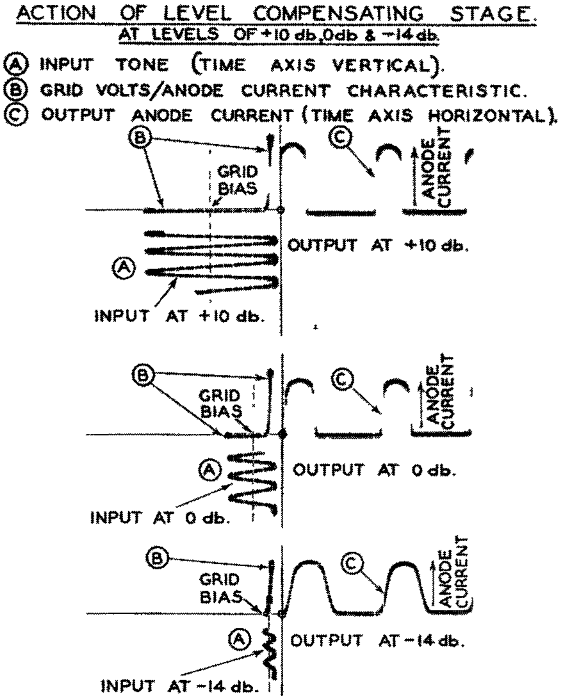

FIG. 8

former will approximately give the lowest peak voltage swing capable of maintaining the constant fundamental output and the latter will give an estimation of the peak amplitude of this output, assuming known anode circuit loads. In practice a finite point is chosen at 15 μA grid current, to determine these quantities, and using the average characteristics of the triode employed at 50 volts on the anode, the grid swing is 1.6 volts r.m.s., the output current being 2.3 mA. The main factor limiting the transformer ratio is the permissible bridging loss of 0.25 db., representing a resistive load of 10,000 ohms on 600 ohms. A ratio of 10 :1 using the standard Post Office transformer of the 48 A type is found to be the maximum permissible, and the bridging loss over the normal telephonic frequency range of 300 to 3000 c.p.s. under working conditions does not exceed 0.25 db., by ensuring that the resonance point occurs in the range 700 to 900 cycles. (See Fig. **9**.) This gives a lower dialling level of 14 db. below 1 mW in 600 ohms, as the limit of the constant output range. It is not anticipated that in practice a level lower than 20 db. will be reached (as postulated in the earlier part of the paper). If the sending level is raised to + 3 db. an equivalent lower level of – 17 db. will be available, and as this sending level corresponds to the level employed on 500/20 trunk ringing, it is not anticipated that cross-talk will be serious. From –17 to –20 db. the dialling performance falls off somewhat, but should still be satisfactory in most cases.

To sum up, the output of the level compensating stage consists of half-wave current pulses whose amplitude rises very slowly with increasing input by an amount necessary to compensate for the reduction in base line of a half-cycle, and give an almost constant fundamental output on the succeeding signal resonant circuits. Moreover, very strong second and third harmonics exist, which are only of importance in that they provide the signalling frequencies when the input tone is the appropriate sub-multiple, thus strengthening the principles outlined previously for the speech immunity device.

Relay Operating Valve Stages.

As intimated in the previous section, the fundamental signal frequencies are selected by simple series resonant circuits of high efficiency, and passed on to the two signal stages, operating relays on either 600 or 750 cycles. The use of such resonant circuits results in adequate selective properties as between the two signals, when combined with the limiting action of the first stage and trigger action of second, and gives a good primary non-signal immunity, whilst the necessary operational bandwidth is secured by other means about to be described.

The voltage/time envelope up to the resonant circuit is practically unaffected by the constants of the circuit, provided the time constant of the constant output stage is suitably chosen. Actually the latter is a compromise between maintaining the grid bias due to the interrupted tone reasonably constant, and at the same time ensuring that the set will be ready to receive a signal of lower level after a short time interval.

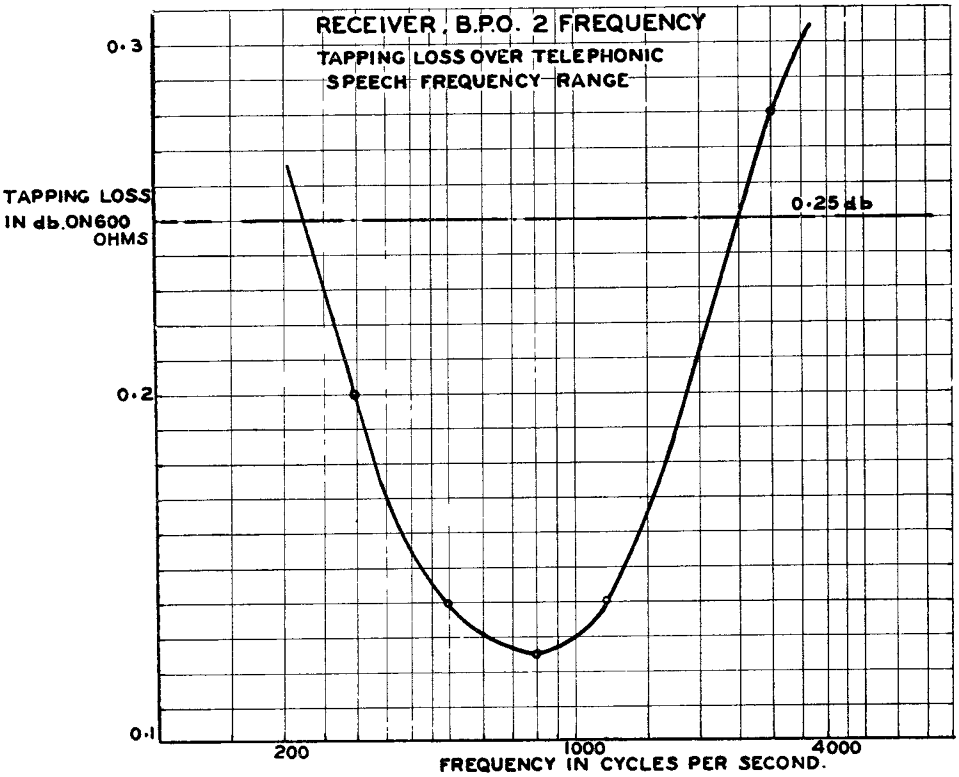

Fig. 9.—B.P.O. 2-Frequency Receiver. Tapping Loss over Telephonic Speech Frequency Range.

On passing through the resonant circuit the voltage/time envelope is radically changed into incremental and decremental periods associated with the incidence and cessation of the tone, so that the signal is never " interrupted " in the sense that it is at the line terminals, when dialling pulses are being transmitted. From this it is obvious that the relay operating stage must have a trigger and detrigger action in order that true make and break currents shall be available for impulsing the relay. Such action is obtainable, particularly at the low battery voltages available, by the use of the well-known rectified reaction stage.

The action of this stage is as follows :—

A thermionic valve is biassed on the grid, from a tapping on the battery not primarily associated with the flow of anode current, so that initially no anode current exists. The operating A.C. potential is applied to the grid and results in small half-wave pulses of anode current by anode bend rectification. The alternating component of these pulses is fed back to a condenser in the grid circuit *via* a rectifier in such a manner as to decrease the static negative grid bias. This provides a fresh working point for the applied A.C. and, owing to the non-linear valve characteristic, a higher mutual conductance, so that the A.C. in the anode circuit is increased. The action is cumulative, provided the input A.C. and therefore the feed back A.C. is sufficient to overcome the power losses in the circuit, which are themselves non-linear. At a certain input potential, the direct component of the anode current rises very rapidly to a value determined by the incidence of a further source of power dissipation, namely, the flow of grid current. For further increase in input potential the rapid change of slope of the grid current characteristic and the flattening of the applied peaks, ensure that the mean anode current does not thereafter rise

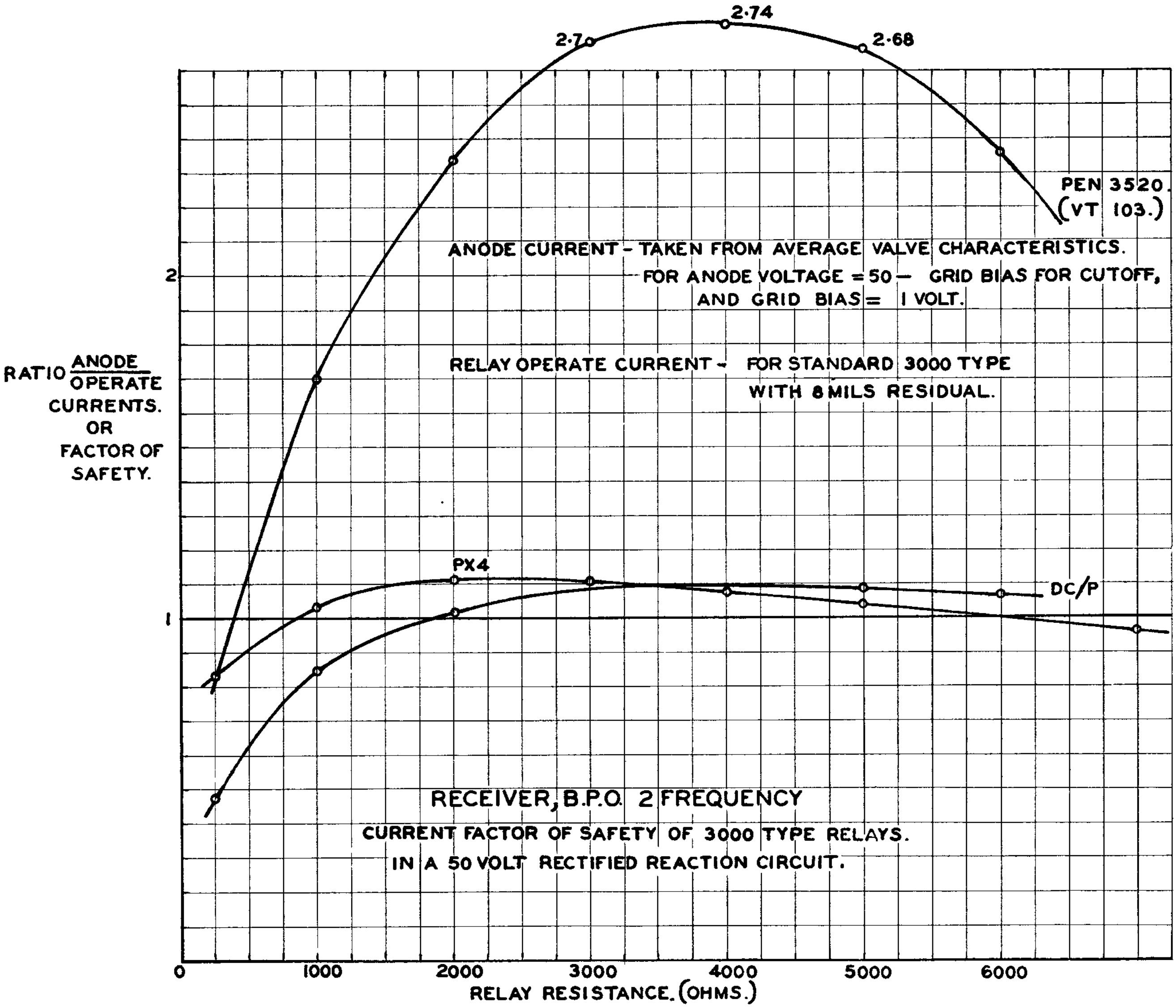

FIG. 10.—B.P.O. 2-FREQUENCY RECEIVER CURRENT FACTOR OF SAFETY OF 3000 TYPE RELAYS IN A 50 VOLT RECTIFIED REACTION CIRCUIT.

appreciably. When the input potential is now decreased, a smaller value will be sufficient to keep the circuit triggered, since the mutual conductance is now much greater than it was at triggering and the power losses can be more easily sustained. However, at some lower level the sustaining action will just be insufficient, allowing the grid bias to increase slightly to the commencement of the poorer mutual conductance characteristic and progressively reducing the A.C. feed-back, so that the anode current falls rapidly to zero again.

To sum up, the device will operate at a certain A.C. voltage and release at a slightly lower one, and will provide a current change of zero to maximum with rapidity.

In practice it is found that the original circuits[16] require modification to make them suitable for impulsing.

For example, the anode current attained when triggered is barely sufficient to impulse reliably telephone type relays when the latter are placed in the anode circuit of a triode and the battery voltage is restricted to 50 volts, of which a considerable fraction must be devoted to providing the static cut-off bias. When the sudden transition from practically no anode current to maximum occurs, the latter, in flowing through the relay resistance, reduces the anode volts, the mutual conductance, and therefore the feed-back. With normal triode valves of the power output class the ratio of anode to operate currents, or factor of safety, plotted against the relay resistance, for a 3000 type relay, barely rises above 1 (using a single C/O contact). (See Fig. **10**—curves for PX4 and DC/P valves.) In addition the sudden reduction in anode volts results in a reduction of the mutual conductance, and in the feed-back A.C. so that the initial anode current secured is less than that which would be obtained, as is shown by slightly increasing the input voltage, when a second maximum is obtained. Also, when considered dynamically, the sudden flow of anode current results in a back E.M.F. from the reactive component of the relay, which will slow up the rise of current in the relay since its effect can be considered as a further temporary reduction in anode volts.

These disadvantages are so great that it is possible to state that reliable impulsing, such as is required for dialling, using 3000 type relays, cannot be obtained from existing triode valves at 50 volts, total battery voltage.

However, by using a pentode valve it is possible to overcome these disadvantages almost completely. In this valve, if the screen grid is maintained at a positive voltage, the anode current falls only very slowly for reduction in anode voltage of about 50%, and the factor of safety rises from 1 at 350 ohms to a maximum of 2.7 at 4000 ohms. (See Fig. **10**—curve for Pen 3520 valve.) Such a valve also gives a clean cut increase in anode current to the correct maximum with increasing input, since the grid volts/anode current characteristic is comparatively uneffected by the anode voltage, and the initial mutual conductance is retained. Similarly the reactive E.M.F. does not reduce the wavefront of the current in the relay to the same extent, as the above type of characteristic implies a high dynamic internal impedance which is comparable with that of the relay.

Other minor alterations and additions to the fundamental circuit have been made, to prevent self oscillation, consistency of operation with widely differing rectifier characteristics, and the incorporation of a series grid resistance to stabilize the triggered grid voltage and reduce the grid current load thrown on the A.C. source.

One other source of trouble exists which is inherent in any form of triggered device, due to the very fact that definite trigger and detrigger voltages exist for any given set-up. (See page 25.)

Methods of overcoming variations in performance of B.P.O. 2-frequency Receiver.

Original Receiver as standardized in Specification *T* 3357. (See Fig. **11**.)

Method of Adjustment.

Since, as shown previously, the voltage/time envelopes for operating the valve relay stages are derived from resonant circuits, the time interval between the operating and release of the relay stage must be adjusted for each receiver, in order that the correct break percentage (when receiving dialled tone pulses) shall be obtained on the relay, for a given input tone make percentage. This means that the time interval between triggering and detriggering of the rectified reaction stage must be such as to produce a current/time pulse of the required type in the relay. Since for any given receiver, the trigger and detrigger voltages will be constant, assuming all other factors constant, then it is only necessary to adjust the full amplitude on the resonant circuit, so that the relay stage operates and releases at the correct points on the incremental and decremental portions of the voltage envelope. This adjustment is conveniently made by experimentally obtaining the correct value of a shunting resistance placed across the transformer feeding the resonant circuit from the level compensating stage. The shunting resistance must obviously be large enough to cater for the most insensitive receiver, and be subdivided closely enough to provide the correct make percentage on the relay.

Apart from internal changes in the receiver, the other external variations not dealt with up to the present are frequency, battery voltage, temperature and life variations.

Frequency Variations.

Using direct transmission of the tones over the V.F. links these are of the order of ± 0.3% or ± 2.3 cycles at 750 cycles, whilst the variations in the initial resonance frequency of the tuned circuits is ± 0.75% or ± 5.63 cycles at 750 cycles—the dialling frequency. Taking the case of a correctly tuned receiver, the variation of make percentage with fre-

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[16] See Bibliography.

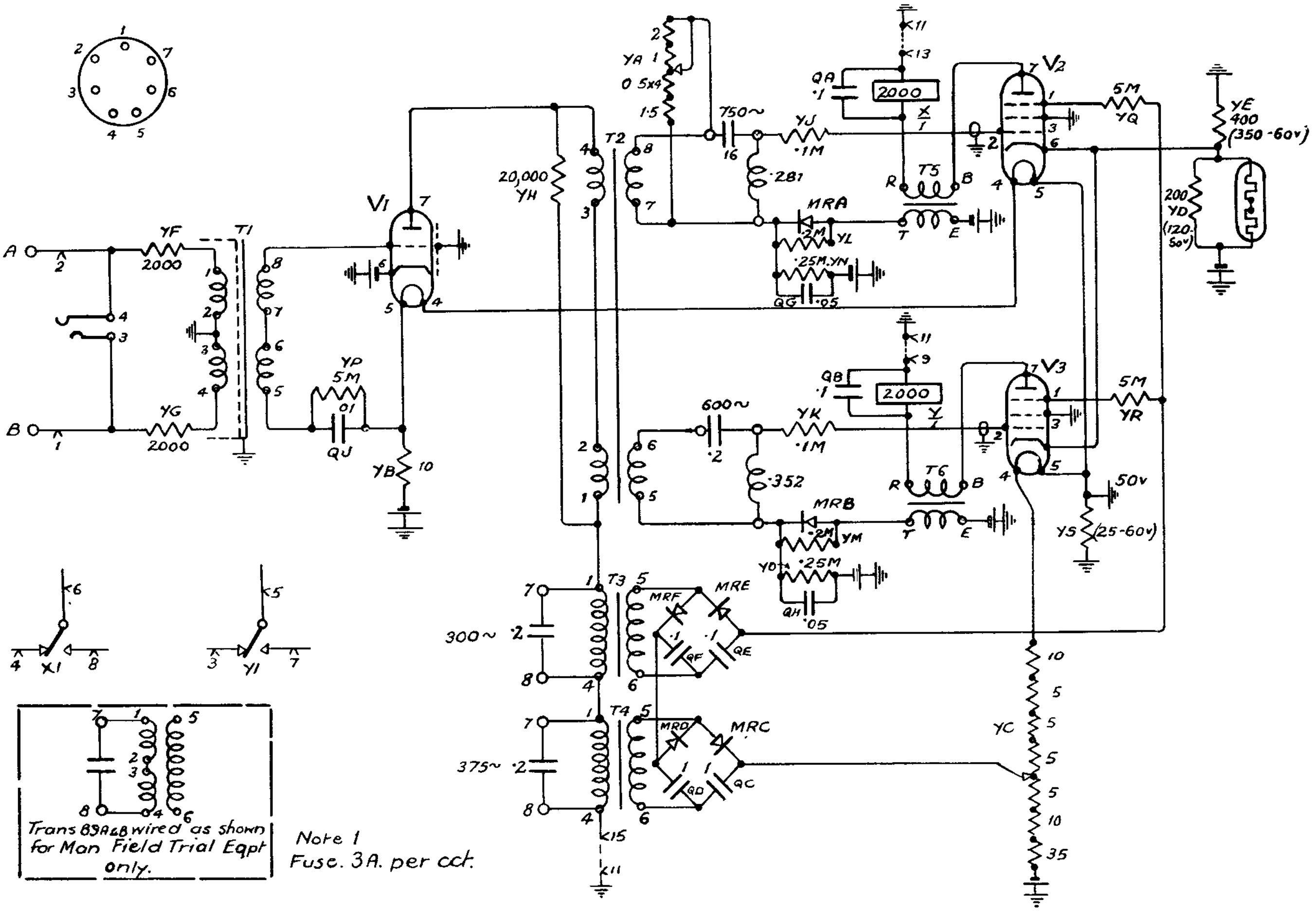

FIG. 11.—B.P.O. 2-FREQUENCY SIGNALLING RECEIVER.

quency will be due to the rapidly diminishing response of the resonant circuit on either side of resonance, but is less than the percentage change in the response. This is due to the production of the beat frequency between the input frequency and the natural response frequency of the circuit, which gives an incremental envelope rising to a greater value than the final response at the impressed frequency. The beat note tends to its maximum amplitude as its cyclic period approaches that of the impulsing periods. (See Fig. **12**.) Now the rectified reaction circuit will trigger on this increased initial amplitude at an earlier point than it would normally and since the detrigger volts are much lower, it will not release on the succeeding fall in amplitude until the detrigger voltage is reached. The use of a high grade resonant circuit does not therefore necessarily imply that the band-width will be correspondingly narrow, and in practice the make percentage change for a change of 10 c.p.s. from resonance is 5% compared with 18.2% for the full tone change in response of the resonant circuit.

Taking into account the initial mistuning of the resonant circuit, ± 0.75%, the distortion due to a frequency change of ± 0.3% (generator) is ± 1.5%.

Battery Voltage Variations.

The battery voltage may change from 46 to 52 volts inclusive at the receiver, but in a large percentage of cases divided battery float supplies will be available in which the range will be from 50.25 to 51.75 volts.

In the normal way, taking the static grid bias from the battery by means of a simple potentiometer would mean a change of 17% in the output make percentage[17]. In order to keep the current/time function on the relay constant therefore, the trigger and detrigger voltages are reduced with reduction in battery voltage and *vice versa,* to counteract this variation, by making the static grid bias vary to a greater extent than the change in supply voltage. This is accomplished by making the arm of the potentiometer used for supplying grid bias, a convenient non-linear resistance, such as a barretter. As shown in the article referred to, this device can be arranged to reduce the variation to 1% on a battery voltage range of 46-52 volts. (See Fig. **13**.) Commercial variations in the barretter and valves, however, permit only of acceptance limits of ± 3%.

Life performance of Valves.

When experience with larger batches of valves was obtained, it became apparent that considerable variations in output were to be expected, especially with the valve in the level compensating stage.

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[17] See Bibliography.

These valves are already selected on an initial performance basis from the normal production radio valves, and it was not to be expected that further selection or ageing would be borne with equanimity by the Contractors, even if the cost were greatly increased. In general, variations in the pentode valve were reasonably small, since a better selection specification could be agreed upon in the absence of any special tests for grid current.

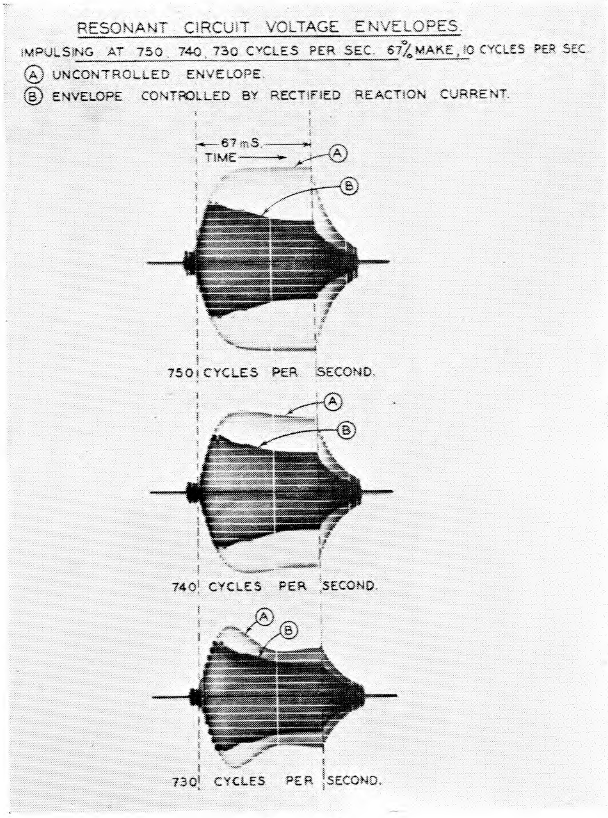

FIG. **12.**

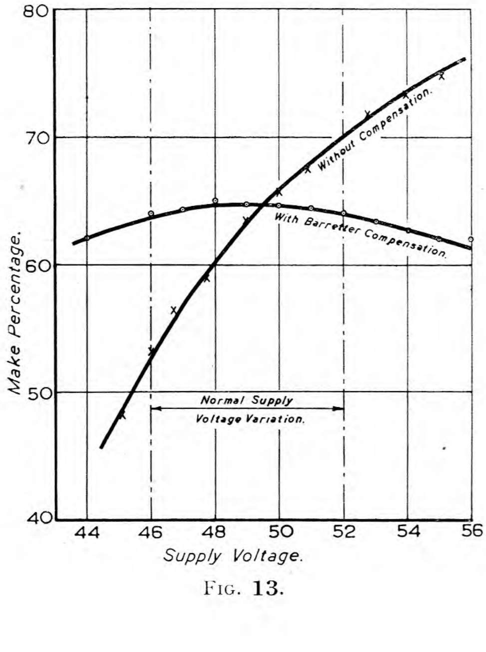

FIG. **13.**

With the triode in the level compensating stage it was found that over an initial period of life which might vary from 150 to 500 hours, the grid volts distance between the anode and the grid current characteristics might vary by some 40%, with corresponding changes in the output . (See page 19.) The use of such a valve is imperative and no great improvement in other makes of the same type was found, so that some means of eliminating this variation is desirable from a maintenance point of view, unless ageing is resorted to.

Temperature Variations.

When large numbers of sets are worked together in the minimum accommodation a temperature rise of 30° or 40° F. is to be expected, when the efficiency of the rectifiers is reduced, the barretter voltage rises, and with dust core resonant circuits the inductances alter. The alteration in the performance will cause a distortion of some -10% on dialling.

From the above it will be seen that initial variations in the components of the receiver are covered by the adjustment of the amplitude on the resonant circuit, to obtain correct performance, whilst methods adopted to stabilize the receiver against the effects of valve ageing and temperature are discussed below.

Diode Stabilized 2-Frequency Receiver.

Reduction of Life Variations and Production of increased band-width characteristic in Level Compensating Stage.

In view of the life-variation in output of the valve in the level compensating stage (See page 19) some form of automatic control on the A.C. voltage output of the valve is indicated, preferably on the resonant circuit, and bearing in mind that band-width requirements of some ± 15 cycles would possibly have to be met in the future, with transmission over carrier links in tandem, a diode-controlled resonant circuit device[18] was found to meet both cases.

The device consists in shunting a rectifier across one of the arms of the series resonant circuit with a bias voltage opposing the current flowing in the forward direction. Then the amplitude of response is restricted to a peak value just exceeding that of the nett bias on the rectifier necessary to pass current in the forward direction, by absorbing the excess energy in the tuned circuit. This method does not occasion any marked distortion of the waveform on the circuit and also restricts both positive and negative amplitudes to almost the same degree. The effect is to give a resonant circuit of high selectivity (*i.e.*, steep slope response) up to the point where the positive bias is overcome, when the gain of the circuit is progressively reduced towards the resonance frequency, resulting in a " flat-topped " response curve. The working amplitude in each arm of the resonant circuit is therefore a function of the positive bias. (See Fig. **14.**)

By this means the make percentage is kept much more constant over a band-width depending on the positive bias on the rectifier, and if, with a triode

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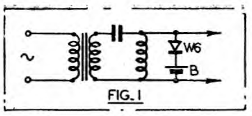
[18] See Bibliography.



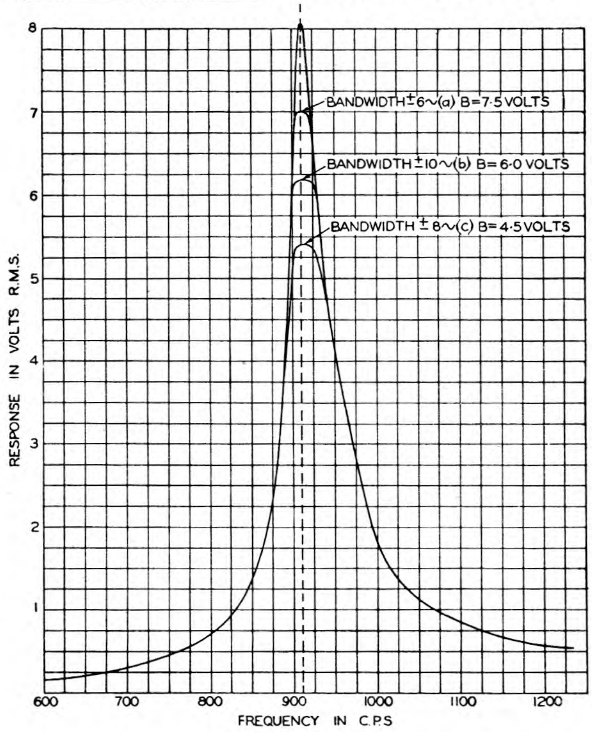


Fig. 14.

valve giving the least output from the level compensating stage the requisite band-width is obtained, then substitution of a valve having a much greater output will not affect the make percentage appreciably but will increase the band-width proportionately (since the excess energy will be absorbed over a wider band of frequencies). The latter is a secondary consideration provided the increase does not seriously affect the speech immunity.

In practice the output from the triode may vary from 2.8 to 1.9 mA after some 3000 hours and would cause a change in the make percentage of some −15%, whereas with the rectifier shunt the change in make percentage is −2%.

To secure this performance it is necessary to use a diode valve, and to control both X and Y circuits it will preferably be an indirectly heated double diode, of the lowest forward resistance commercially attainable (in order that the power absorbing function shall have the maximum effect on the resonant circuit whose internal working impedance may be some 100 ohms). These types of diodes are now becoming common especially with the introduction of television and forward resistances of 300 ohms per diode can be secured.

Band-width response with Diode Stabilizer.

Taking the minimum output from the first stage, the minimum band-width requirements will be obtained with a certain bias, and it is desirable that this value of bias shall remain unaltered with internal variations in the rectified reaction stage. The method of achieving this will be described later.

A symmetrical configuration of Band-width Characteristic.

The band-width response secured is not however constant with such a simple application, when impulsing. It is found that the mean response curve from say 720 to 780 cycles is not horizontal but is inclined at an angle, especially when the input level is greater than zero db. The series resonant circuit arranged so that the voltage on the inductance is applied to the relay stage, acts as a high pass filter and in consequence the sine wave on the inductance is distorted at one point by the small half wave input pulse from the secondary of the level compensating stage transformer. The wave-form on the capacity is not so distorted but cannot be used, since the D.C. potentials on the resonant circuit are different from those on the relay stage. This distortion does not remain at the same point on the sine wave with change in frequency about resonance, due to alteration in the phase angle (which may change by 120° for ± 30 c.p.s.), and gives a fictitious amplitude for triggering the rectified reaction stage earlier or later as the frequency is on one or the other side of resonance. (See Fig. **15**—curves A and C.)

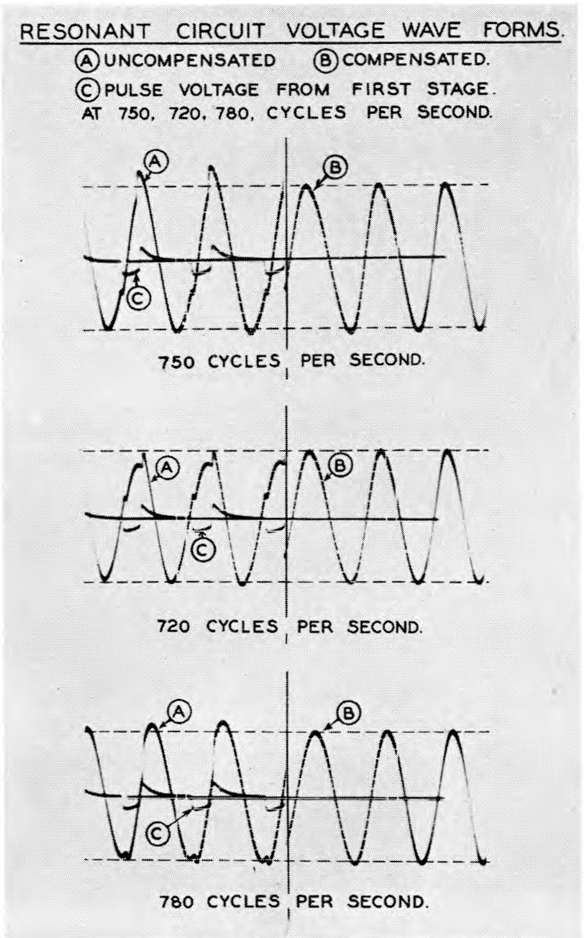


Fig. 15.

To overcome this a similar voltage from a further secondary winding on the output transformer of the level compensating stage is arranged in series opposition with the output to the relay stage so that the true sine wave is applied to the latter. (See Fig. **15**, curves B.) As the same phenomenon affects the working of the diode, this is connected across the condenser arm of the resonant circuit.

Subsidiary Valleys in the Band-width Characteristic.

Having made the mean characteristic symmetrical about the true resonance point, any given characteristic shows valleys at frequencies of ± 12.5, ± 37.5, etc., cycles from resonance. The explanation of this phenomenon is not yet clearly established, but various means of reducing the depth of the valleys are known.

It appears that at resonance and at ± 25, ± 50 c.p.s., etc., from resonance the decremental alternating voltage existing at the beginning of a fresh tone pulse joins up with the incremental voltage wave-form, but that at ± 12.5, ± 37.5, etc., the two alternating frequencies do not join up, and produce a cancellation effect over a period of 1 cycle. From this it is seen that a loss of 1 cycle in time may be incurred at these frequencies giving possible valleys of 1.5 to 2% which agrees with experimental tests. If means can be found of reducing the decremental amplitude, or of the ratio of final decremental amplitude to initial trigger amplitude, then these valleys will disappear. This is verified experimentally by decreasing the tone make percentage or the impulsing speed, when smooth symmetrical band-width responses are obtained, because the decremental period has been made long enough for the decrement voltage to reach zero before the incidence of the next tone pulse. (See Fig. **16**—upper set of curves.)

Such valleys must therefore be a characteristic of this circuit, although a method was found of reducing their depth by decreasing the ratio of final decrement volts to trigger volts. Incidentally, these valleys are employed to give a rapid cut-off to make percentage response by including just as many peaks as will give the required band-width. Thus the minimum band-width is up to the beginning of the second valley on either side of resonance—*i.e.*, a band-width of ± 25 cycles, which suits the requirements admirably.

The variation in making percentage over such a band-width is then from 0% distortion at resonance to −1.5% distortion at the extreme frequencies.

Initial and Life Variations in Rectified Reaction and means adopted to reduce them and improve overall performance.

As pointed out earlier, any trigger action device gives a very poor performance unless the operating voltage envelope with time is unaltered, and the trigger and detrigger voltages remain constant with internal changes. The former requirement has been met in the design by the level compensating stage with its diode controlled output, so that the voltage envelope applied to the rectified reaction stage is independent within 1 or 2% of line level, frequency, and internal variations.

The trigger and detrigger voltages vary profoundly with the internal conditions of the rectified reaction stage, so that small changes in the components with life, or external conditions will seriously affect the distortion. An instance in point is the effect of temperature changes on such a circuit as that in the original receiver. (See page 23.)

A method of self-control has been evolved for rectified reaction circuits, or any similar trigger operated device such as a gas filled tube, which to a very great extent makes such a stage self compensating for internal or external changes. This method uses the triggered direct anode current as a control of the magnitude of the operating A.C. potential, when the circuit is triggered, but leaves the circuit free to trigger at its own voltage. This is accomplished by using a constant passing voltage sufficiently great to allow the worst stage (in terms of trigger volts) to trigger, and opposing this voltage with one produced by the flow of anode current when triggered. Thus if the control voltage alters due to internal or external changes, then the control exercized is in the opposite sense, tending to restore the *status quo* and if the maximum voltage which would be attained in the absence of a control is much greater than that needed for the worst trigger voltage, then any variation in the latter will be accommodated on a wave-front of high slope (volts per millisecond) so that only a small proportion of the total operate time will be lost. In all cases moreover, the circuit will always trigger.

From the discussion under " Reduction of Life Variations," etc., it will be seen that the conditions outlined in the previous paragraph are already present. The diode control on the output of the level compensating stage at the resonant circuit, requires a positive bias which need only be of the correct value when the rectified reaction circuit has triggered; if an excess positive bias is applied before triggering the whole of the available voltage from the resonant circuit will be passed on so that the rectified reaction circuit can trigger, and this maximum voltage will greatly exceed the trigger voltage over the band-width required, since this is the method of obtaining the band-width and of controlling the output from the level compensating stage, thus producing the steep wave-front effect. When the circuit has triggered, the excess positive bias is reduced by an opposing voltage generated by the flow of anode current in a suitable potentiometer and the nett bias thus obtained can be made equivalent in its effect to the constant bias control, keeping the band-width and output controlled in the level compensating stage as before. (See Fig. **12**—curves B.)

With the incorporation of this device, the distortions due to changes in the components and external conditions on the rectified reaction circuits are reduced to small quantities comparable with the distortions obtained in the level compensating stage, so that it can now be said that the diode stabilizes the whole receiver. In particular the following changes in external conditions are rendered susceptible to more complete treatment.

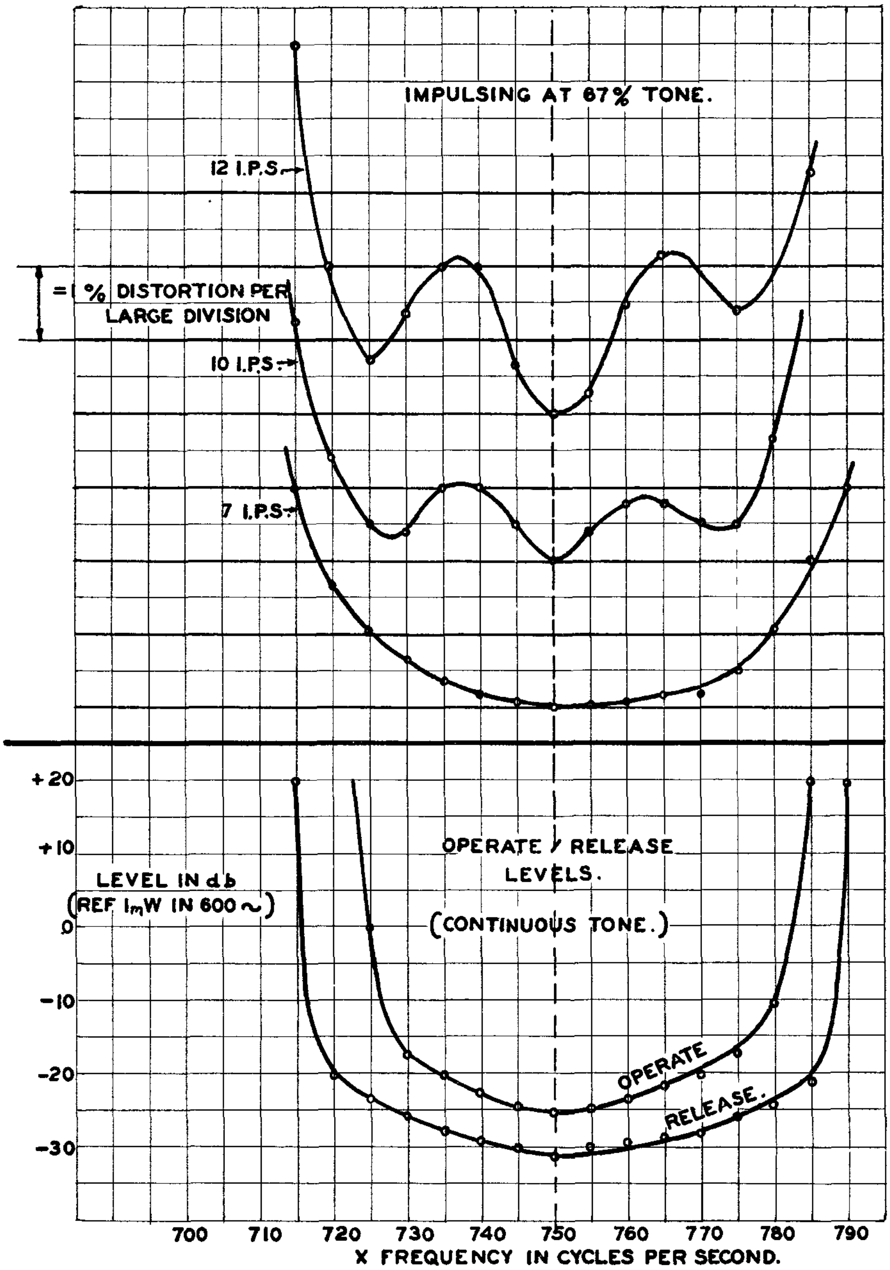


FIG. 16.—B.P.O. 2-FREQUENCY RECEIVER. BANDWIDTH RESPONSE CURVES.

Battery Voltage Variations.

Without the barretter circuit the distortion from 46 to 52 volts is now of the same order as could be guaranteed for the original receiver (with a barretter circuit) when extreme conditions of components and barretters were encountered. If the barretter circuit is retained, the compensation required is much less and can be easily obtained with wide variations in the barretter characteristics.

Temperature Variations.

In the stabilized receiver the temperature distortion is reduced by more than 3 times, giving a distortion temperature coefficient of -0.06% per 1°F.

In conducting temperature tests on the stabilized receiver, since the distortion coefficient was so small, the control bias was altered at each temperature to give zero distortion, and by subtracting the actual control bias obtained the difference gave the amount by which this bias would have to change to give zero distortion. Plotting this with respect to temperature gave a straight line, whose slope expressed as a temperature coefficient on a resistance of 38 ohms, was $+ 0.003$. This 38 ohms is the resistance providing the constant passing bias on the diode, so that by winding it of copper wire, whose temperature coefficient is $+ 0.004$, the increase of the passing voltage with temperature should approximately compensate for the various temperature effects in the receiver. In practice it was found that from temperatures of 38°F. to 135°F., the distortion did not exceed ± 0.8%. Thus the stabilized receiver can be made practically immune from temperature changes.

Circuit details and performance of diode stabilized receiver.

Circuit details.

Referring to the diagram (Fig. **17**) it will be seen that the two signal frequency relays X and Y are operated by two identical pentode valve stages, V2 and V3. Discrimination between X and Y frequencies is obtained by resonant transformers T5 and T6, fed from the output transformer of the level compensating stage V1. The working voltage on the resonant transformers are controlled by the D.C. bias on the double diode V4. Immunity of operation against speech and automatic tones is provided by the resonant transformers T3 and T4 working into the rectifier networks providing a negative bias to the suppressor grids of V2 and V3. Taking the component stages from the line terminals A, B, the first stage is

The Level Compensating Stage.

This comprises a medium impedance triode valve V1, in whose grid/cathode circuit are the secondary of the step-up transformer from the line, and a 0.01 μF condenser shunted by 5 megohms. The primary is fed through two 2000 ohm resistors from the line, has its centre point earthed, and is screened from the secondary.

With the 1 :10 ratio transformer used, the tapping loss is a maximum of 0.25 db. at 300 and 3000 cycles, falling to a minimum of 0.13 db. at 800 cycles. (See Fig. **9**.) Any received tone at a level greater than −14 db. produces half wave pulses of anode current whose energy content at the fundamental frequency is kept constant (See page 19) up to +20 db. so that feeding these pulses into the series resonant transformers T5 and T6 by means of a step-down transformer T2 gives wave-forms at the fundamental signalling frequencies of constant amplitude between these levels.

The secondaries of these transformers are fed to the respective X and Y rectified reaction stages. Due to the high pass filter characteristics of these tuned transformers the sinusoidal voltage on the transformer has impressed on it the exciting pulses with a certain phase displacement and causes asymmetrical band-width characteristics to be obtained. (See page 24, and Fig. **15**.) This distortion is removed from the X transformer output (at the 1 :1 ratio) by feeding a similar winding on the output transformer in series with the secondary but in phase opposition to the pulse voltage on the secondary. It is not necessary to do this with the Y transformer, as this frequency is only used for pulse signals of such time duration that variations of 1 or 2% make no difference.

The amplitudes of the voltages on the resonant transformers T5 and T6 are governed by the bias on a double diode valve V4, such that with minimum conditions in this stage a minimum band-width of ± 20 cycles is obtained, over which the response is sensibly flat. This bias is slightly variable and in practice is derived from two opposing voltages, as will be explained in the next section, but for the present purpose can be considered as of constant nominal value. If the output from the valve is greater (due to a better valve, etc.) then the voltage on the resonant transformer will not rise appreciably since it is a function of the control bias on the diode, but the band-width over which this control is exercised will be greater.

The signal frequency voltage outputs from this stage are therefore stabilized with changes in level, band-width, and valve characteristics. In order to exert this stabilizing influence fully the diode used must have an internal impedance of the same order as the working internal impedance of the resonant transformer, and is approximately 400 ohms.

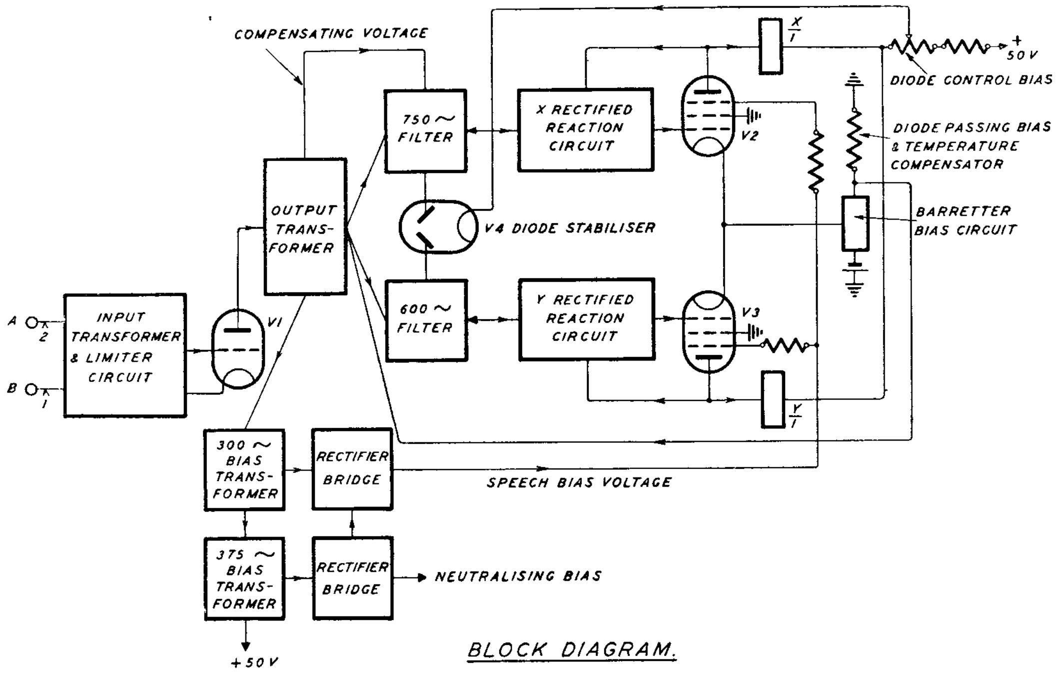
The Rectified Reaction Relay Stages.

As these are identical and only the X stage must give a performance with a minimum distortion, this stage will be described.

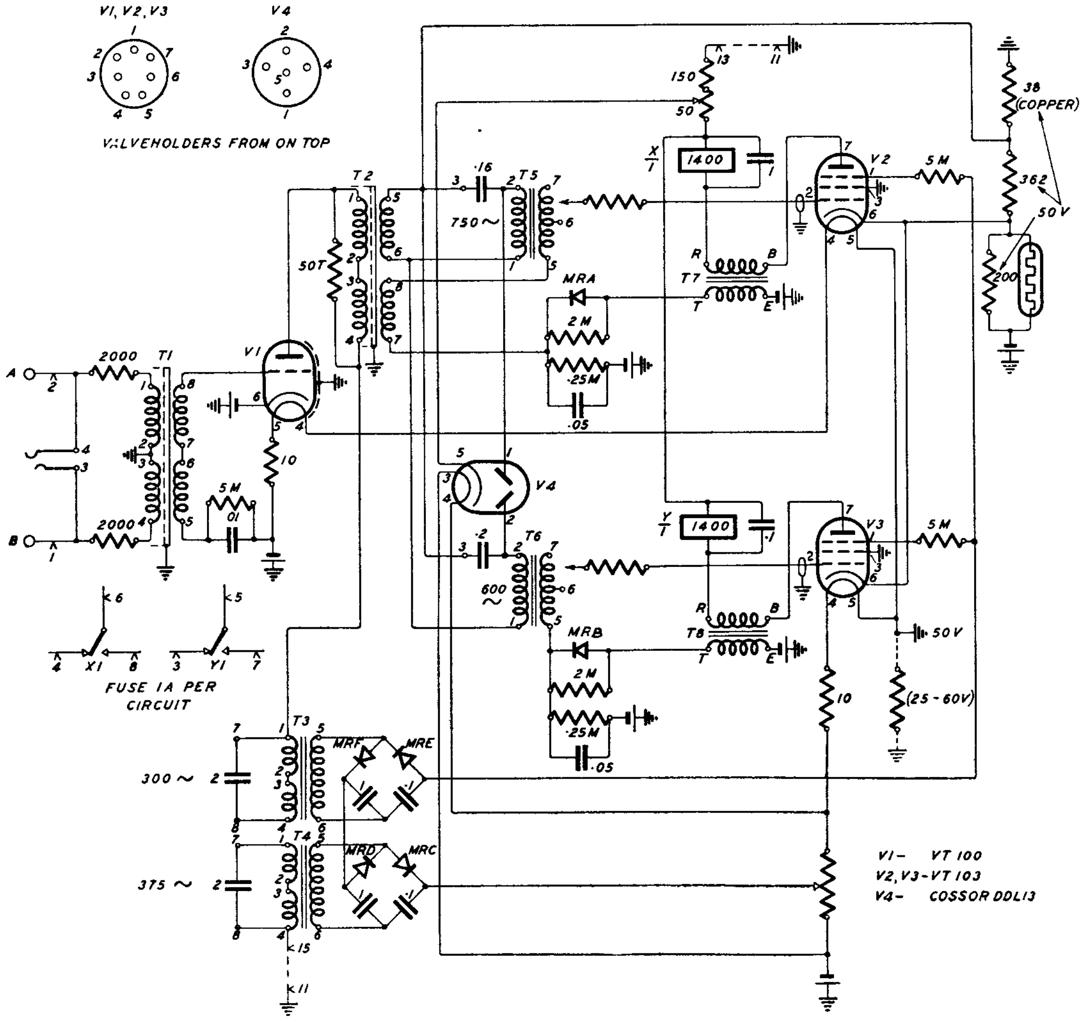
For any given stage the time of operation of the relay depends on the time interval between the trigger and detrigger voltages on the voltage envelope applied to the stage. As the latter will have an increment and decrement time for one pulse of tone, it is apparent that the relative magnitude of the envelope voltage must be altered until the correct make time or percentage is secured on the relay, when dialling tone pulses are received. This is catered for by tappings on the secondaries of T5 and T6, a fine adjustment being provided by a limited range to the control bias voltage on the diode.

Having allowed for the initial divergencies in trigger and detrigger voltages as between one stage and another, a further stabilizing feature is introduced to ensure that changes in the components with life or external conditions shall be minimized in their effect. This consists of using the triggered anode current to bring the bias on the diode down to the right value when the circuit has triggered. (See page 25.) By this means changes in trigger and detrigger voltages are accommodated on the steep slope wave-fronts of the envelope on T5, and ensure that the minimum time interval is lost. (See Fig. **12**—curves B.) To effect this type of control a positive passing voltage is placed on the diode from a 38 ohm resistor which is part of the barretter shunt circuit on the battery, so that with the worst conditions throughout the receiver the maximum voltage on T5 passed by the diode is much greater than that required to trigger V2. Included in the return path of the diode cathode is a resistor in the anode circuit of V2, so that when V2 triggers, the anode current flowing through this resistor sets up a voltage opposing the passing voltage, and reducing it to the value required by band-width considerations.

In order to compensate for the changes in output with temperature the passing voltage produced by the 38 ohm resistor is made to change in a calculated



BLOCK DIAGRAM.



CIRCUIT DIAGRAM.

Fig. 17.—B.P.O. 2-Frequency, Diode Stabilized Receiver.

manner, by winding it of copper wire, as opposed to eureka wire on the other resistors. (See page 26.)

With the functional operation of the circuit stabilized as shown, changes due to battery voltage variations from 46 to 52 are quite small, and are compensated for by incorporating a barretter circuit control of the static grid bias on V2. (See page 26.) Since the control to be exerted is only of a secondary nature, this permits of wide variations in barretter characteristics.

Immunity of Operation from Speech and Non-signal Frequencies.

As the level compensating stage will automatically generate strong harmonics of the input frequency, it is only necessary to guard against operation of the signal stages by sub-harmonics, when considering operation by non-signal frequencies of a repeated nature (*i.e.*, automatic and other signalling tones). However, generation of the signal frequencies by speech, with or without an accompanying frequency which is not a sub-harmonic, may occur, in which case scientific protection cannot be devised, and purely random methods must be used. Generation of such frequencies is not prolonged and is invariably preceded or followed by frequencies which will provide a bias from sub-multiple resonant circuits, and if these biasses are large enough the incipient operation of the signal stages will be cut short so that the maximum time of operation will be of the order of 20 to 50 milliseconds. Such small operate times are guarded against in the relay sets, by imposing a small delay period of 200-300 ms. on the X frequency which does not prevent signalling by tone pulses, and making the signal operation on Y dependent on reception of 2 pulses within 0.5 secs. In addition, the clearing signal condition which would give the greatest trouble due to speech operation, is further protected by making it dependent on operation in succession by both signalling frequencies.

To secure the high biasses required, transformers T3 and T4, resonant at 300 and 375 cycles (the first sub-multiples of the signalling frequencies) are placed in the anode circuit of the level compensating stage. Their secondaries supply two voltage doubler rectifier circuits in series, the D.C. bias being applied between the suppressor grids and cathodes of the rectified reaction valves, *via* 5 megohm resistors. In this manner, practically no load conditions are present and it is possible to generate 80 volts bias at each sub-multiple frequency which is 3 times the anode current cut-off bias required on the suppressor grids. Owing, moreover, to the response of these circuits to sub-multiples of their own frequency, biasses are secured at these lower frequencies, so that by suitably designing the response characteristics of the circuits, an effective bias is generated at all frequencies below and including the first sub-multiples of the signalling frequencies. (See Fig. **18**—curves (*a*)).

Since a certain amount of bias is generated at the signalling frequencies and more particularly by shock excitation on the dialling frequency, these biasses are neutralized as regards their effect on the suppressor grid/cathode circuit, by a positive voltage with respect to the cathode. The presence of this positive

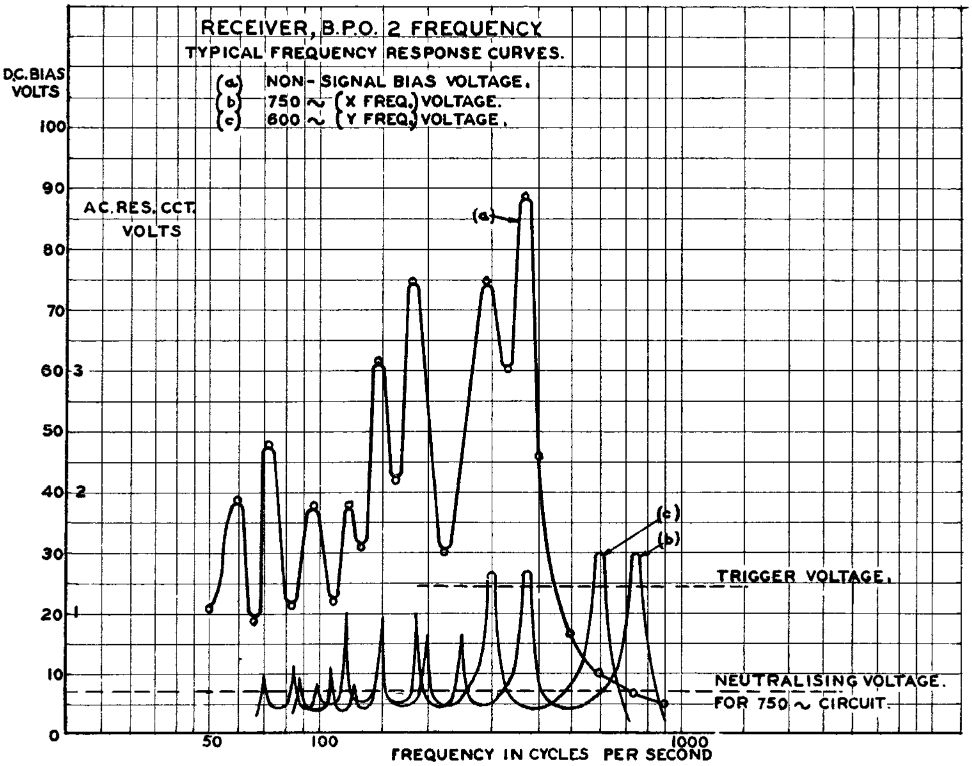


Fig. 18.—B.P.O. 2-Frequency Receiver. Typical Frequency Response Curves.

voltage does not affect the anode current of the valves V2 and V3 since the stopper resistance of 5 megohms absorbs nearly all of it, if a small suppressor grid current flows.

The voice immunity device is therefore practically instantaneous when required, has a small hangover period, and in no way affects the signalling path, since the residual bias is neutralized and the absorption of power from the anode circuit of the level compensating stage is negligible at the signalling frequency.

Details of performance of Major Components.

Valves.

V1 is a medium impedance triode, having a 13 volt 0.2 amp. heater wired in series with V2 across the battery. The main performance required is an output current of between 1.9 and 2.8 mA at 50 volts on the anode at the grid bias which produces 15 μA grid current, initially and with life. (See page 24.)

V2 and V3 are indirectly heated "power" pentodes, the heater being rated at 35 volts, 0.2 amp., having the suppressor grid terminated on pin 1. At 43 screen volts (7 volts lost due to grid bias) the average anode current in the triggered condition through the 1400 ohm relay is 10.5 mA. Since the dynamic impedance of these valves is some 35,000 ohms, good impulsing conditions are readily obtainable in the relay although its D.C. resistance and reactance are high.

V4 is an indirectly heated double diode, with a 13 volts, 0.2 ampere heater connected in series with V3 across the battery. The internal resistance in the forward direction is of the order of 400 ohms.

The life of these valves is expected to be some 5,000 hours, although this figure may not apply in all cases to V1, since the relationship between the grid and anode current characteristics is liable to changes which cannot be calculated. It is anticipated, however, that the majority should maintain an output greater than 1.9 mA for this period, and since changes in output down to this figure will be compensated for, no great variation in performance of the receiver will result.

Resonant Transformers.

These are all of the same constructional type, using the standard G.P.O. pot, bobbin and core dimensions, whilst the condenser is mounted in a detachable recessed base, so that when mounted it projects through the base-plate. The core material is of μ-metal, with an adjustable gap to secure the correct inductance. The secondaries are of fine wire and are used only for voltage transferring purposes, thus allowing the best performance to be secured from the primary.

Rectifiers.

These are all of the W.4 type, since all are used mainly for voltage purposes. Those used in the rectified reaction circuits are shunted by a resistance low enough to ensure that changes in back resistance of the rectifier shall not have any appreciable effect on the performance.

Relays.

The 3000 type relay construction is used, with the exception that the core material is of nickel-iron having a small corehead. Standard C/O springs and pressures are used with restricted adjustments and tolerances of 8 ± 2, 29 ± 2 mils on the residual and travel respectively. This gives an operate current factor of safety of nearly 2 :1, and ensures that impulse speeds up to 12 i.p.s. can be used.

Overall performance on Dialling.

In testing these receivers, variations in the break contact percentage, or more conveniently the distortion expressed as the difference between the input and output break contact percentages, is measured for changes in the applied dialling tone, one at a time and assuming all other variable factors are constant at their nominal values. The sign of the distortion is taken as positive when it indicates that a gain in the make percentage through the receiver has occurred and *vice versa*. The overall performance may be assessed by the addition of distortions of like polarity. It is realized that this method does not necessarily give a complete picture of the overall performance when all factors are in one direction and to demonstrate this point a target diagram for the receiver showing the greatest divergence from the originating dial target obtainable with various combinations of the possible variations quoted below, is shown in Fig. **19**.

The following are the worst distortion figures as measured on a limited number of receivers, taking into account variations in components between maximum and minimum limits :—

Received Level Variations.

Taking zero level (1 mW continuous tone into 600 ohms) as the reference point, line levels between −14 db. and +10 db. give a maximum distortion of +1%. (See Fig. **20**.)

Distortion of Signals due to Long Lines.

Experience on such distortion has been limited to trials conducted over repeatered lines, when no detectable effect was found.

Frequency Variations.

Taking the correct frequency and a correctly tuned receiver as the reference point, the maximum distortion between ±20 cycles band-width is −2%. (See Fig. **16**.)

Battery Voltage Variations.

Taking 50 volts as the reference, the maximum distortion between 46 volts and 52 volts is ±1%. (See Fig. **20**.)

Impulsing Speed.

Taking 10 i.p.s. as the reference, the maximum distortion between 7 and 12 i.p.s. is +1%. (See Fig. **20**.)

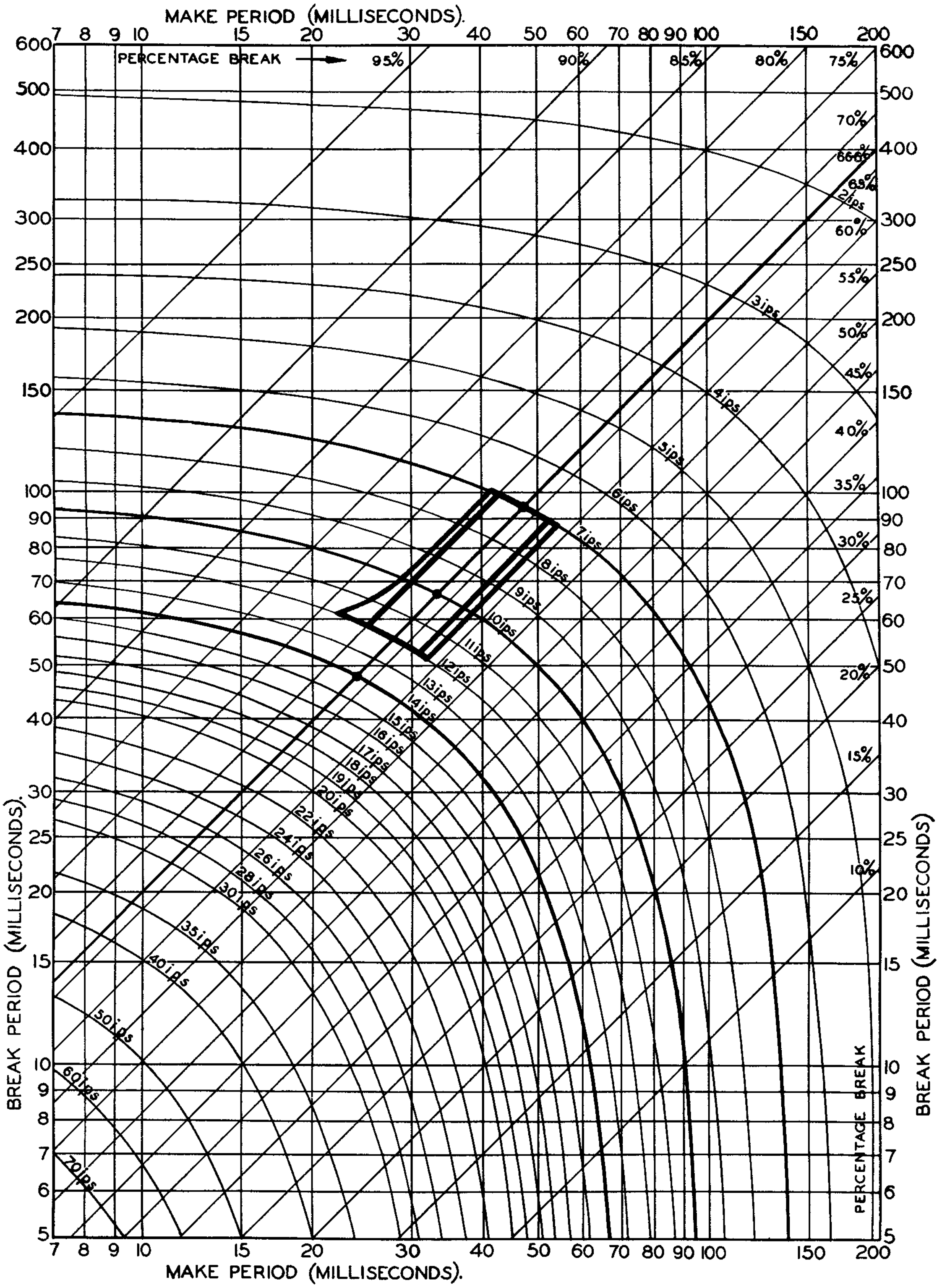


Fig. 19.—Target Diagram of Diode Stabilized Receiver under Worst Conditions at each Test Point. Originating Dial Target (7-12 ips., 63 to 70% Break).

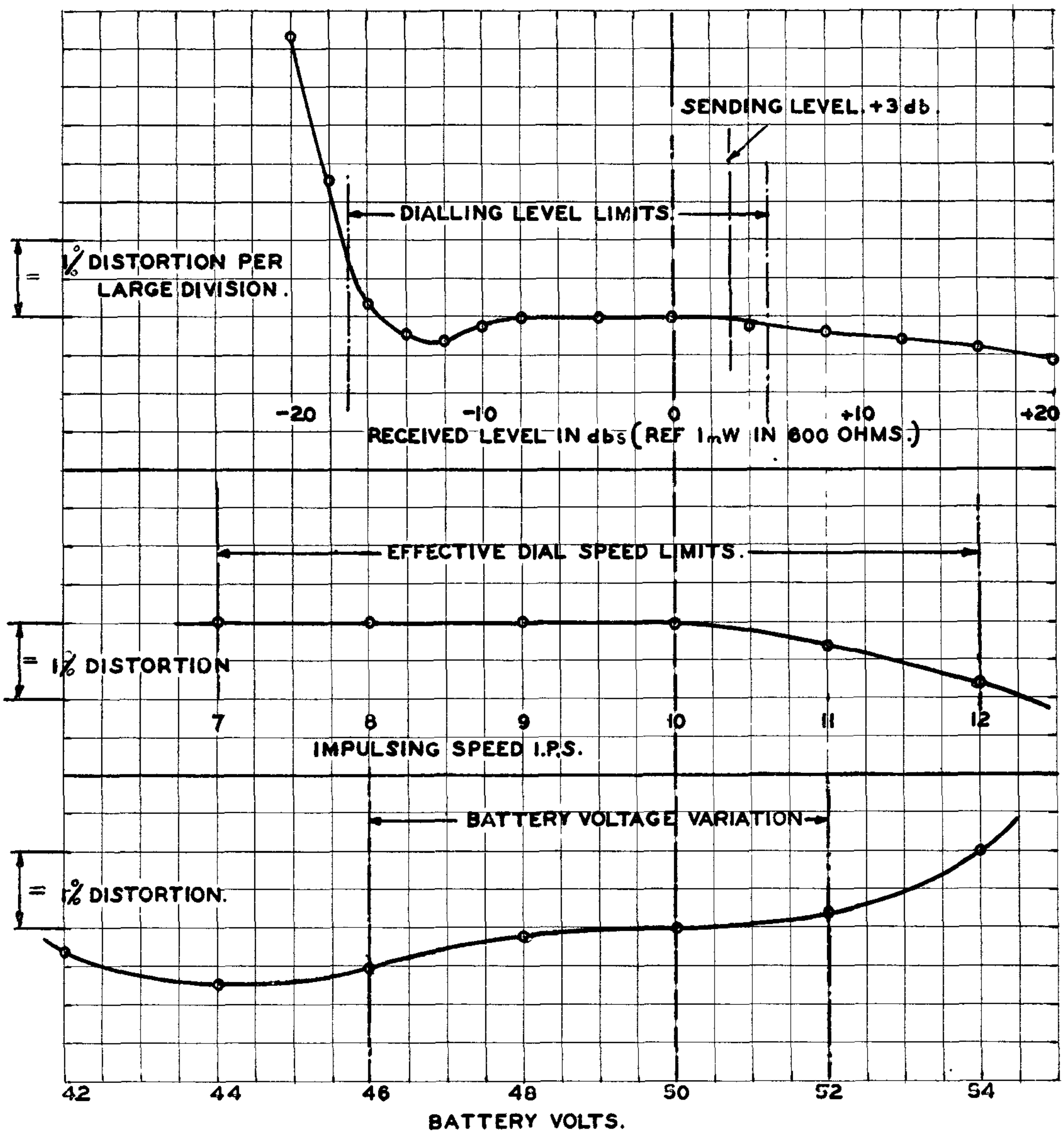


Fig. 20.—B.P.O. 2-Frequency Receiver. Dialling Performance with Received Level, Impulsing Speed and Battery Voltage.

Impulse Ratio Variations.

There is no distortion due to variation of impulse ratio over the range 75% to 50% tone per impulse, at impulsing speeds between 7 and 12 i.p.s. and with the most adverse relay adjustment.

Life Variations.

As far as experience goes this is mainly a function of V1, and taking the change of a maximum output value to a minimum output the maximum distortion is −2%.

Temperature Variations.

Taking the reference point at 60°F. the maximum distortion between 38°F. and 135°F. is ±1%.

Hence, taking a receiver at the beginning of its life, set up under certain temperature conditions, the overall distortion should be +3% to −4%; without maintenance and with life and wide temperature changes, these figures may become +4% to −7%.

Operate Lags and Operating Levels.

The operate lags of the receiver under various practical conditions are shown in Fig. **21**.

The operate lag to signal tones is shown to be some 20 ms. over a range of levels of +10 to −18 db. When the signal tone is *immediately* preceded by a non-signal tone, the maximum lag is some 140 ms. when the level difference is 30 db. and the non-signal tone produces no " speech " bias, and is constant at 200 ms. for all level ratios if it does produce bias. The latter is important when signalling through the breaks in N.U. tone, and shows that ample time is available for the clearing signal to operate.

Conclusion.

A telephone V.F. signalling system in which signals can be lost in the transmission system and jammed by speech and other disturbances, is bound to be less certain in performing some of its functions than other methods of signalling. It is also bound to be more complicated, more expensive and to require a higher standard of maintenance than other methods of signalling. In designing the system described in this paper, the signals were selected to ensure maximum reliability in operating the equipment, and have since proved to be satisfactory. The equipment required to translate the signals into their circuit functions can claim the advantages of operation entirely from the 50V exchange battery, the use of fixed sending levels of tone without the necessity for hybrid coils with their balances, and the absence of difficult relay timing and adjustment, at a cost which is economic in relation to the facilities secured. The adjustment and maintenance of the signal receivers requires a technique new to automatic exchanges but not beyond the powers of the maintenance staff to master. Successful field trials have proved the reliability of the equipment and the ability of the staff to maintain it.

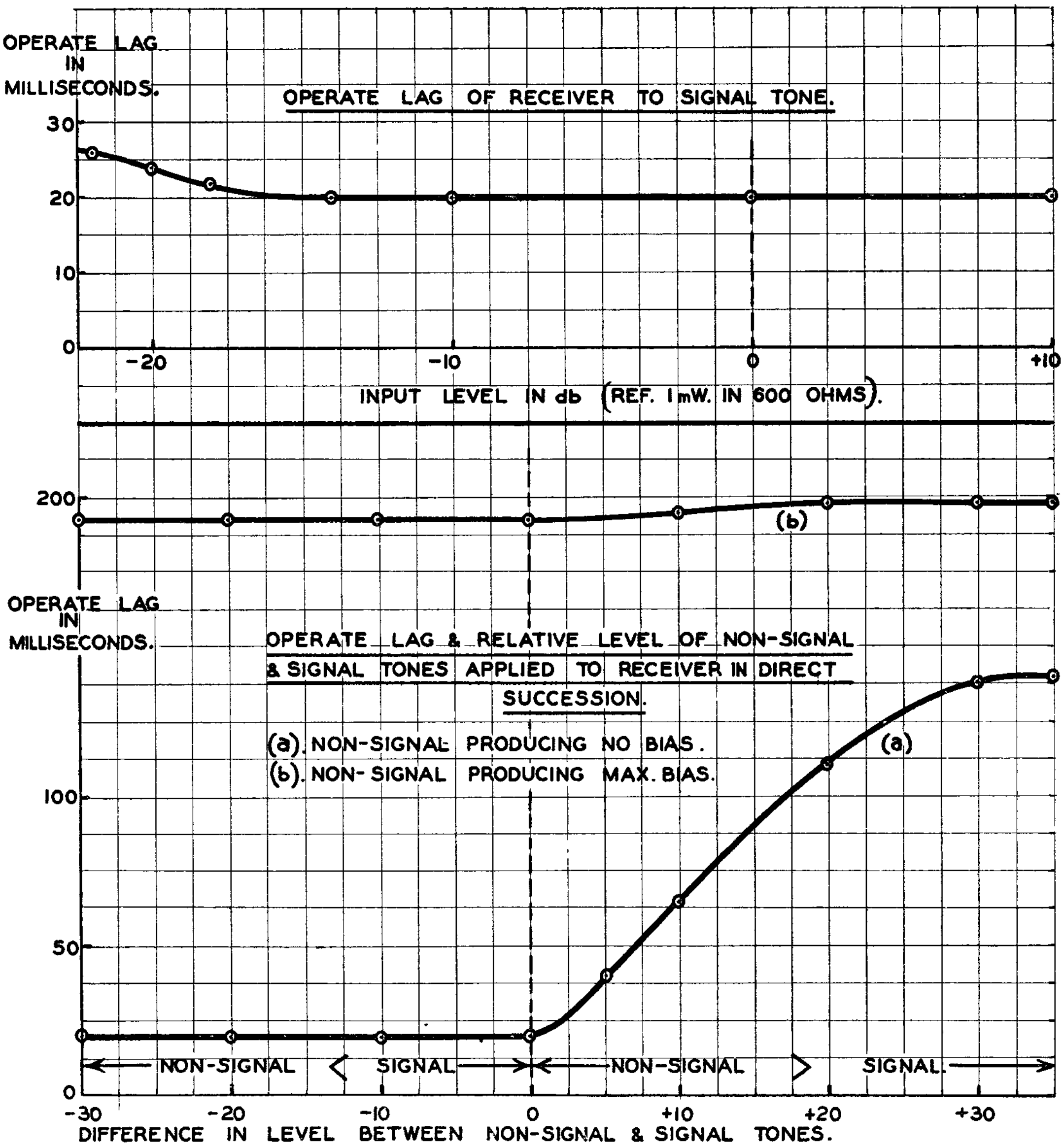


Fig. 21.—B.P.O. 2-Frequency Receiver.—Operate Lags. Over Operation Level Range of +10 to −20 db. (Ref. 1mW. in 600 Ohms.)

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