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A Cathode Ray Impulse Measuring Equipment

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Equipment is described with which the instantaneous impulse distortions experienced in automatic telephone networks may be measured on a target diagram basis. Use is made of a cathode ray tube to display the target diagram.

Introduction.

THE subject of impulsing as applied to automatic systems necessitates the study of make and break times from contacts. At the normal speed and ratio of impulsing (10 i.p.s., 67 per cent. break) as used by the British Post Office, the make and break times are 33 and 67 mS, but as these impulses are invariably originated by a dial or similar mechanism certain limits have to be allowed. Although it is usual to consider impulsing performance in terms of speed and ratio, since these are easily measured by simple testing apparatus (provided a sufficient number of impulses are available), a more fundamental method of consideration is to deal with the make and break times in milliseconds. If these times, for any given impulse, are plotted on graph paper with the make times as abscissæ and the break times as ordinates, a point can be found which completely defines this impulse.[1, 2]

If an automatic system, designed to work from a dial or other impulse generator is tested at various combinations of make and break times until failure occurs, the points at which failure occurs may be joined together in a closed loop known as the " system target." The " generator target " may also be plotted on the same graph, by taking the extreme limits of make and break times of the generated impulses. The relative positions of the latter diagram and the system diagram enable an estimate to be easily formed of the safety factor in the system as a whole. In order that visual estimation shall be accurate, the scales for make and break times are plotted logarithmically so that equal dimensions shall represent equal percentage variations.

These areas are known as " target diagrams " ; Fig. 1 shows a type commonly used. By joining points, the sum of the make and break times of which is constant, a series of curved lines is obtained which represent constant speeds of impulsing. Similarly, by joining points for which the ratio of break time to total impulse time is constant, a series of lines representing constant impulse break ratio is obtained. Since the time scales are logarithmic and of the same dimensions, the break percentage lines are parallel and inclined at an angle of 45° to the axes. In this manner the characteristics of an impulse may be correlated, in terms of speed and ratio, with quantities measured by existing methods.

On the basis of such a graph, the normal dial limit variations are shown as a target composed of two break percentage lines at 70 and 63 per cent.,

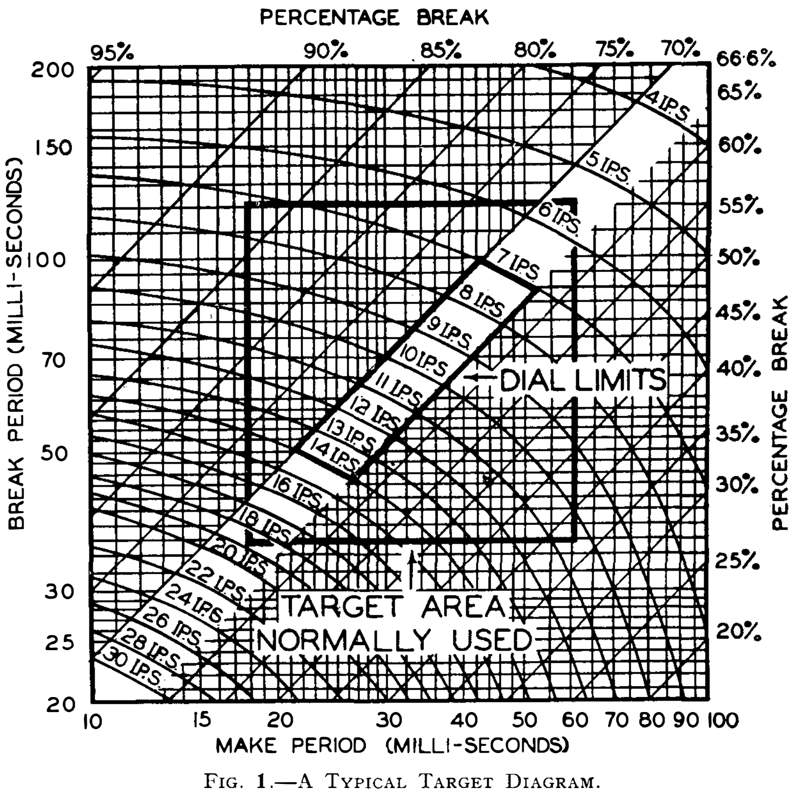


FIG. 1.—A TYPICAL TARGET DIAGRAM.

[1] *P.O.E.E.J.*, Vol. 20, p. 269.
[2] *Engineering Supplement to the Siemens Magazine*, No. 182, July, 1940.

the other sides of the target being completed by the portions of the speed curves at 7 and 14 i.p.s. as required. The area of this figure defines the total limits of the average make and break time permissible on the originating dial.

In another form of this diagram the break lines are marked in degrees, where 180° corresponds to 100 per cent. break. This is due to the use of a mechanical impulse generator, the rotary mechanism of which can be adjusted to give any break percentage in terms of angular displacement.

Method of Application to Impulse Transmission Systems.

From the above it will be seen that the principal use of this method has been the determination of the failure points of various automatic telephone systems, mainly in the laboratory ; the target diagram has also been used as a convenient means of record for the comparison of the efficiencies of automatic systems. The present equipment was designed not so much for testing any one automatic system as for determining whether the linking-up of various impulse systems is feasible from the point of view of the known failure points of the systems. A typical example of this is the recent introduction of 2-frequency signalling and dialling on trunk lines, linking up two or more automatic systems.

The application of the method is therefore somewhat similar to that used in line transmission measurements. An impulse generator, the output of which is capable of adjustment over the whole of the anticipated range of impulses likely to be encountered at any stage of the system, is applied to the test apparatus, and a measuring equipment at a remote portion of the system shows the resulting distorted impulses in the form of a target diagram. By comparing this with the known breakdown diagram at this point, it is immediately seen whether the system will work, and also an indication of the factor of safety is given.

It should be remembered therefore when reading the following sections, that the target diagram display at the reception point will consist of a distorted version of the input impulses. The success of such a system of testing will, of course, depend on the speed and accuracy with which the distorted diagrams can be obtained, and considerable attention has been paid to these factors in the design of the apparatus.

Methods of Testing under Target Diagram Conditions.

Usual Method.—This consists of employing a rotary impulse generator the speed of which can be varied between required limits, and the make percentage of which can also be varied. A series of pulses, usually 9 in number, is applied to the test equipment from this machine, and the speed or percentage altered until the equipment fails. Alternatively, the extreme limits of the dial target are used, one at a time, and the output make and break times are then recorded on some form of oscillograph using a strip of paper moving with constant velocity. The mean make and break times are assessed from this oscillogram, as are also the maximum and minimum times, and these points are then plotted on the target diagram.

It will be seen that the method is laborious, and it takes a matter of hours to carry out a complete target diagram test ; in addition to which it involves the separate investigation of mean, minimum and maximum impulses in a train.

Present Method.—It was considered that, provided an indicating equipment could be devised to show the performance of each and every impulse, it would be unnecessary to provide more than one, or at the most two, test impulses of the same nature. Provided that successive test impulses differ only in a slight degree (i.e. by, say, 1 i.p.s. or 5 per cent. break), the response of the apparatus under test will not differ appreciably from that which would be obtained by continuous test impulses at a given speed and percentage.

Taking the dial target area shown in Fig. **1** as an example ; if single pulses at each speed from 7 to 14 i.p.s. on the 63 and 70 per cent. lines, plus one at 7 i.p.s. 67 per cent., and one at 14 i.p.s. 67 per cent., are generated in cyclic fashion by progression around the rectangle, then 18 pulses per cycle are needed to test the system. One cycle can therefore be accomplished in some 2 seconds, or 4 seconds if each pulse is duplicated.

The device capable of providing such a series of cyclic test pulses is known as the impulse generator, and will be described in a subsequent article.

It was also considered that a cathode-ray equipment could be developed in which the deflections on the X and Y axes would be proportional to the logarithm of the make and break times, so that when the above cyclic train of impulses was applied to it the dial target would be displayed. By using a screen possessing a long after-glow it would be possible to retain a visual impression of the whole target. This device, known as an impulse measuring equipment, can be calibrated by superposing on the screen a transparency of the target graph such as Fig. **1**. If the impulse-repetition link is then interposed between the impulse generator and the impulse-measuring equipment, the resulting display on the latter will be distorted. By comparison with the area normally occupied by the cyclic trains of test impulses, the distortion introduced by the link may be assessed.

As this test can be repeated cyclically, changes in the variables in the link (for instance, V.F. equipment) can be made so as to produce the worst target in a rapid manner. If this target falls within limits necessary for the correct functioning of succeeding automatic equipment, then it is known that the system will work, independently of any other test made on the equipment. Similarly, by extending the dial target generator to the originating end of a V.F. link it is possible to assess the overall performance.

The method is rapid and is capable of self-calibration, since the dial target generator can be checked before use against the measuring equipment, and both can be checked against a make percentage meter of the usual type by causing the generator to deliver a series of constant make percentage pulses.

Design Principles of the Impulse Equipment

Automatic switching mechanisms have been designed to work on impulses received from a dial or similar generator which are such that the circuit is first seized by a loop, the dial springs being closed at this period. The impulses are then generated by opening and closing the loop, the final condition being that of a loop. The fundamental conception of an impulse used in the design of this equipment is a break period followed by a make period.

If the apparatus is to show an impulse as a single co-ordinate point depending for its position on the time periods of the break and make, it is obvious that

(*a*) no display can take place until the make period has elapsed, and

(*b*) the voltages for such display must be stored until it is convenient to use them.

The design of this apparatus is, therefore, largely influenced by this storage and delay principle. The following section describes the elements of the circuit for obtaining a voltage proportional to the logarithm of the break and make periods which also enables these voltages to be stored. The delay action is secured by the use of uni-selectors.

The Time Measuring and Storage Circuit.

It is well known that if a condenser C be charged via a resistance R from a battery of V volts, the voltage v existing across the condenser at time t from the instant of switching on is given by

$$\frac{v}{V} = 1 - \epsilon^{-t/CR}$$

At a preliminary inspection it does not appear that this type of relation would give a voltage proportional to log t, giving in fact a relation of the form t proportional to log v. But it is found that the equation is a very close approximation to the required one over a fairly wide range. This can best be shown by plotting the curve against t as independent variable using a logarithmic scale. This is given in Fig. **2**, and it will be seen that the curve is very nearly linear between values of v/V from about 0·3 to 0·9. Variation of the time constant CR shifts the curve to the left or right without altering its shape, so that the time range covered may be altered by adjustment of either the resistance R or capacitance C. The ratio of maximum to minimum times covered by the linear portion of the curve is, however, constant and is of the order of $3\frac{1}{2}$ to 1.

A target area corresponding to make times of about 20-60 mS and break times of about 40-120 mS can be accommodated with a logarithmic scale to an accuracy of the required order. Moreover, such an area will include most points at which measurements are required, assuming that the distortions being investigated are not too great. This area is therefore taken as the basis of design, and is shown in Fig. **1** by the thick line square. Where it is desired to employ a larger target area, suitable scales may be derived from the curve of Fig. **2**; specimen scales covering the whole of Fig. **1** are shown at the side of Fig. **2**. The form of such a derived scale will be logarithmic at its central portion, with the divisions becoming more cramped at both the upper and lower ends of the scale. This only slightly modifies the appearance of the target graph at its edges. In view of the simplicity of the basic circuit and the fact that it is not anticipated that it will be necessary to exceed the logarithmic limits very often, no attempt has been made to evolve a circuit producing a wider logarithmic range. The impossibility of attaining the ideal characteristic will be apparent when it is realised that when t = 0, log t = $-\infty$, i.e. an infinitely large negative deflection is required, and this is obviously unattainable.

In addition, the circuit possesses the quality of storage, which is indispensable if deflections are to be made which are due to the combined effect of make and break periods of one impulse, since these periods occur one after the other.

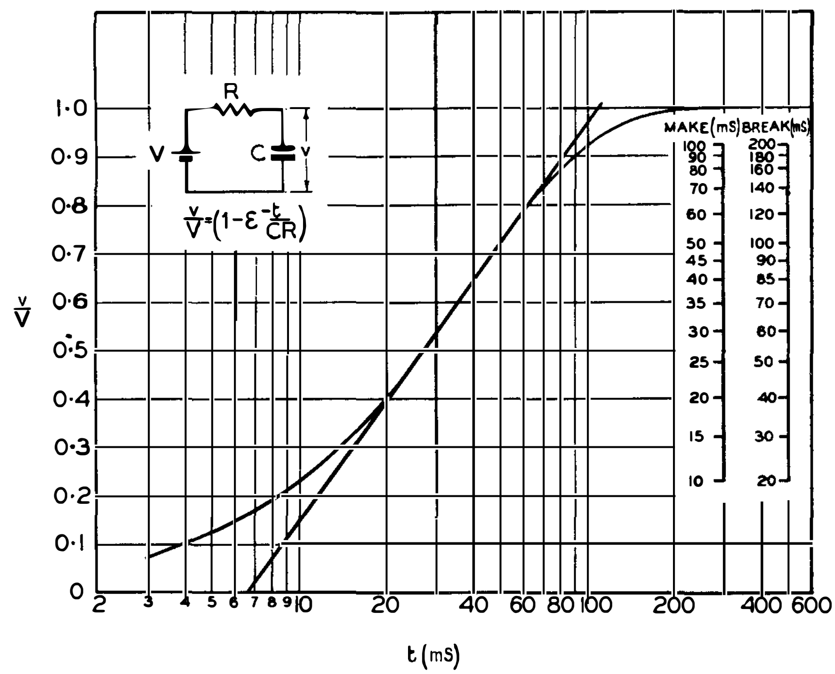


FIG. 2.—GRAPH SHOWING RELATION BETWEEN CONDENSER POTENTIAL AND TIME.

Use of Uniselectors as Delay Elements.

If two condensers are arranged in circuits similar to that outlined above so that the charging circuits are completed during the make and break time respectively of the contact under test, then, after one impulse, the voltages on the condensers will be dependent, in the manner described, on the make and break times of the contact respectively. A pair of uniselectors is employed to connect a fresh pair of condensers to the charging circuits at each impulse so that the voltages are stored on pairs of condensers in turn.

The basic circuit arrangement is shown in Fig. **3**. The condensers are arranged in two groups of five, connected to the first five contacts of arc 1 of each of the uniselectors. The drive circuits (not shown on the diagram) are arranged so that switch 2 moves forward just after the impulsing contact

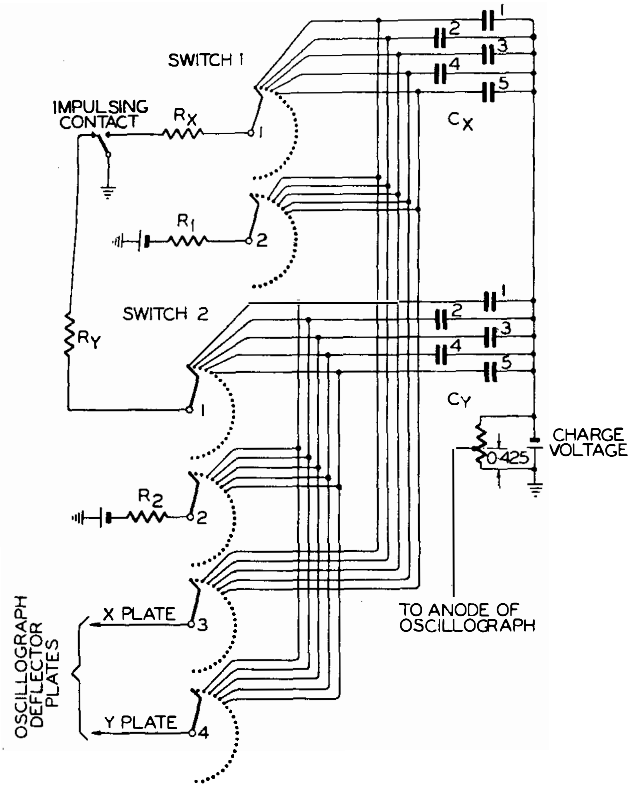


FIG. 3.—BASIC CIRCUIT ARRANGEMENT.

operates, and switch 1 moves forward just after it releases. In this manner the voltage rise on the condensers is unaffected by the switch movements since the latter always occur when the charging circuit is interrupted by the contact under test.

Arcs 3 and 4 of switch 2 are arranged to connect the X and Y deflector plates of the oscillograph to the first pair of condensers Cx, CY after two steps of the second switch. The delay between the charging of the condensers and the connection of the oscillograph plates is necessary, because if connection were made at the next step the X plate would be connected during the charging period of condenser Cx_1, so that a steady spot deflection could not be obtained.

With the third step of each switch the first pair of condensers is discharged through the small resistances R_1 and R_2 via arcs 2 of the respective switches. By repeating the bank connections on all the switch arcs so that each connection recurs at every sixth contact, operation on continuous impulsing can be arranged.

It will be appreciated that since the automatic system normally gives break times twice the make times, and the charging voltage and deflectional sensitivity of the tube may be assumed equal for both X and Y deflections, the time constant of the break contact charging circuit must be twice that of the make contact circuit. This could be obtained by making condensers CY twice the capacitance of Cx, but has been attained by making RY twice Rx and using the same values of condenser on X and Y deflections.

Application of the Deflection Voltages to the Cathode-Ray Tube.

Since the nominal value of the impulses used in automatic systems is 10 i.p.s., 67 per cent. break, the target area is arranged so that this point is central. It is therefore necessary that the oscillograph beam shall be undeflected when the voltages on a corresponding pair of condensers are appropriate to this point. Reference to Fig. **2** shows that the mid-point of the logarithmic portion of the charging curve may be taken at a value v/V of approximately 0·575. Since the break and make times of the standard impulse are in the ratio 2 : 1, the time constants of the two charging circuits must be in this ratio if the mid-point of the charging curve is to coincide with the mid-points of the X and Y scales. When this condition is realised, both X and Y deflecting plates of the cathode ray tube must be given an initial bias of 0·575 of the charging voltage with respect to the anode to locate the spot at the mid-point of the target area under conditions of standard impulsing.

The necessary bias is obtained by raising the anode to a voltage of 0·425 times the charge voltage with respect to earth (Fig. **3**.). The voltage is obtained by joiningthe anodeto a tapping on a resistance connected across the charging voltage, represented in Fig. **3** by the battery.

As the deflection on the oscillograph should be zero when the standard impulses (10 i.p.s., 67 per cent. break) are applied, this condition forms a convenient means of setting up the time constants of the X and Y charging circuits, since in this condition the sensitivities of deflection are immaterial. The resistances Rx and RY are variable, and are adjusted for zero deflection with the standard impulsing. The initial position of the spot, in the absence of any input, can be separately lined up with the centre of the transparency, which may have engraved on it a target graph similar to Fig. **1**.

The only remaining adjustment to ensure that the display is correct, consists in altering the overall sensitivity of deflection to its correct value. This may be done by applying impulses of known type, the target point of which is well removed from the centre of the graph (such as 14 i.p.s., 67 per cent. break) and varying the sensitivity adjustment provided to give the right deflection. A more satisfactory method is to apply a cyclic repetition of speeds and percentages corresponding to a known target area and obtained from the impulse generator.

DETAILS OF GENERAL INTEREST

Improved Operation of the Uniselectors.

One of the major troubles encountered in the design of the control circuit in both the measuring equipment and the generator, is the difficulty of ensuring satisfactory operation of the uniselectors, using existing methods. It will be obvious that, if the switches are to be actuated by the impulses generated during the course of a target cycle, or from faulty impulses, they must be capable of satisfactory operation on impulses the speed and ratio of which are well outside the limits normally envisaged in automatic circuit design. It has been found experimentally that the minimum energisation period for satisfactory operation with existing circuits is of the order of 12 to 15 mS so that, at 14 i.p.s., reliable operation cannot be obtained with a make ratio of less than 20 per cent. This lies very close to the normal target area and leaves little margin for cases where an extended target area is required; hence the need for a considerable improvement in the switch performance.

If the coils of the uniselector driving magnet are connected in parallel instead of in series as is normal with these switches, the operating lag of the switch will be reduced. The time constant of the circuit remains the same since both the total resistance and total inductance are reduced in the ratio 4 : 1, but the final current in each coil has twice its previous value so that the time taken to reach the operate value is reduced. When the armature is operated, a smaller value of current will be sufficient to hold the mechanism, and this can be arranged as indicated in Fig. 4 by allowing the rotary interrupter springs d.m. to introduce an additional series resistance R into the circuit. When the impulsing contact (I.C.)

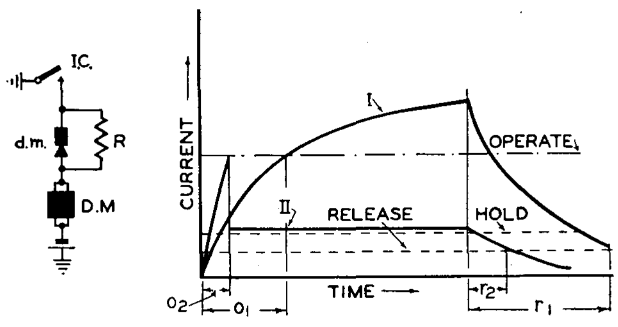


FIG. 4.—MODIFIED UNISELECTOR DRIVE CIRCUIT.

opens, the current commences to decay from this reduced value, and therefore reaches the release value in a shorter time than in the normal circuit. The types of current wave-form are shown in Fig. 4, curve I referring to the normal series connection of the coils, and curve II to the modified circuit. The minimum energisation period for satisfactory operation is reduced by this circuit ar angement to 5 mS, which gives ample margin to cover most of the requirements. Reference to curve II shows that, over the major portion of the impulse cycle, the current in the magnet coils is much less than with the normal series connection; hence the tendency for the windings to overheat during long periods of continuous operation is removed; neither can they be burnt out by prolonged seizure.

Performance of the Measuring Equipment on Local and Distant Impulsing Contacts.

At the outset it was considered desirable that this circuit should be capable of testing impulses from a local or from a distant contact. Tests could then be made with the generator at one end of a junction and the measuring equipment at the other end. This would assist in localising a cause of distortion to one or other exchange.

Use has been made in the measuring equipment of a polarised telegraph-type relay to achieve the necessary uniformity of impulsing performance with variations in lead resistance. The polarising winding is energised via a resistance, so that normally the tongue is held against the back contact. The test contact is wired to the operating winding via a limiting resistance.

Tests on this circuit element have shown that the output from the relay is distortionless within about 1 mS for resistances in series with the operating coil between some 400 and 2,000 ohms when the polarising current is 5 mA and the relay adjusted to give a contact pressure of 15 gms. with this value of polarising current in either coil. The limiting resistance is made 400 ohms to ensure a minimum value of lead resistance, so that the permissible loop resistance is 1,600 ohms. Tests with artificial cable have also given satisfactory results.

Visual Observation of Measuring Equipment.

For visual observation a transparent screen is fitted over the end of the tube on which is engraved a target area corresponding to the central portion of Fig. 1. The target display obtained from the apparatus under test is then depicted on the tube screen, and the impulse characteristics can be read directly off the engraving. With this method of observation the target diagram can be continuously displayed and the effects of changes in adjustments or component values of the apparatus under test immediately detected.

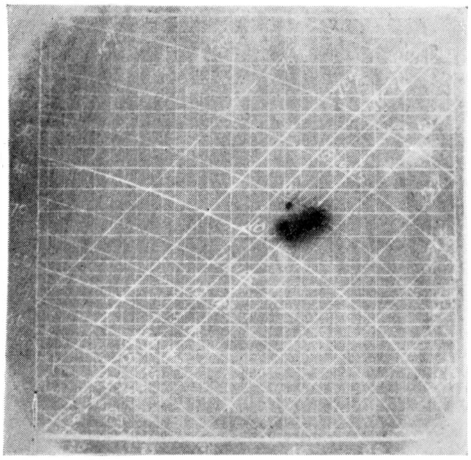
Photographic Recording of Measurements.

Where permanent records of target diagrams are required, it is easy to arrange to photograph the oscillograph screen. Facilities are provided for illuminating the screen from the rear by a diffused light, so that the resultant photograph taken directly on oscillograph paper appears as a dull grey background against which the interposed screen engravings are indicated as white lines. The test impulse target diagram points, as transmitted by the repeating link under test, appear as heavy black dots against the background.

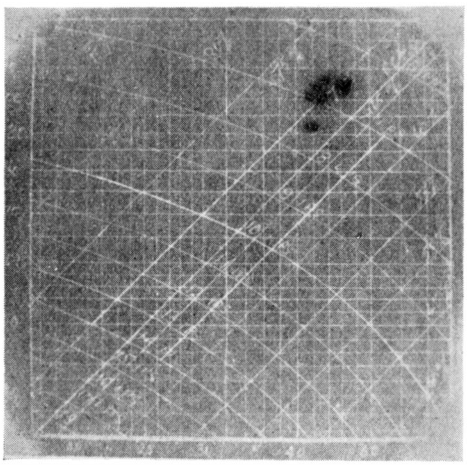
It will be realised that the display consists of a series of spots, each representing the combined make and break times of one impulse. Photographs Nos. 1-3 of Fig. 5 show typical examples of the photographic record obtained. The performance of various impulse generators as demonstrated by the apparatus is shown, and a more detailed discussion of these results will be found later.

General Use of the Impulse Measuring Equipment.

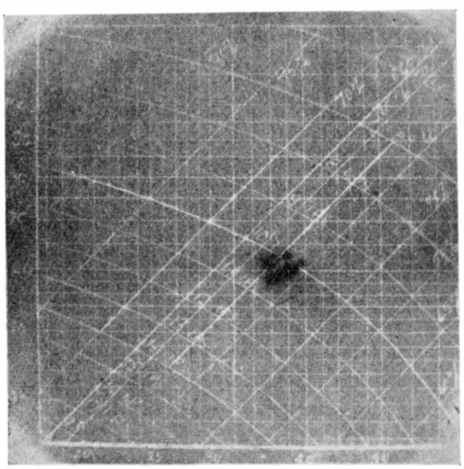
The impulse measuring unit can be used individually to test impulses given by any form of generating apparatus. In particular, mechanical regenerators or dials may be tested so as to verify that the impulses given lie within the required limits both as regards speed and ratio. With a dial, a given train of impulses will not contain the same number of make periods as break periods, since at the end of the train, the dial springs close, giving in effect a very long make period for the last impulse. Due to the delay between the charging of condensers which are included in the equipment and the display of the charges on the cathode-ray tube, the last impulse of a train is not



1. *Typical Subscriber's Dial.*



2. 7 *I.P.S. Dial.*



3. 39 *Pulses from a Regenerator.*

Fig. **5**.—Typical Oscillograms.

displayed, and the last pair of condensers to be connected to the charging circuits acquire charges equivalent to the break time of the last impulse and a very long make time. If, however, the impulsing springs are connected in series with the off-normal springs of the dial, and the latter is re-operated immediately after the test train has been dialled, an artificial make time corresponding to the last impulse will be generated, the length of which is dependent upon the time for which the dial is normal. When the dial is finally released, the switches of the measuring equipment step forward, and the first subsequent indication of the spot gives the break time of the last impulse of the test train together with the artificially generated make time.

The characteristics of each individual impulse can therefore be displayed, and in addition the correct operation of the off-normal springs can be verified.

Discussion of some Test Results shown in Photographs. (Fig. **5**.)

The plates of Fig. **5** consist of untouched reproductions of photographs taken during the course of experimental work with the equipment.

Nos. 1, 2 and 3 show the performance of a dial in normal adjustment, a dial adjusted to 7 i.ps., and a regenerator respectively. The main point of interest is the extent of the divergency of individual pulses from a given mean, together with occasional pulses differing widely from the bulk. A careful inspection of No. 5 will show a triangular grouping of the bulk of the pulses, due to the three impulsing cams on the regenerator. This effect is very striking when viewed directly on the apparatus, as is also the general reduction in speed on some models, as the driving spring unwinds.

General Use with an Impulse Generator.

When used in conjunction with an impulse generator of the type previously referred to, and which will be described in a subsequent article, the measuring equipment may be used both for general exchange maintenance testing and for laboratory tests on impulsing problems in general. For the first use a target may be originated by the generator at the outgoing end of a circuit and the resulting target examined by the measuring unit at any subsequent switching stage. This will enable any faulty apparatus to be quickly located. At present no facilities exist for fault localisation of impulsing stages in tandem in this manner, and it is considered that for this reason the equipment should find a considerable field of usefulness.

For laboratory testing, the distortion target of any type or number of impulse repeating stages may be displayed and comparative data quickly obtained and permanently recorded by photographs. The use of the equipment for this purpose would result in a considerable saving of time in the collection of such data, as compared with existing testing methods. Moreover, the effects of changes in component values or adjustments in circuits of this type could be readily assessed.

Photographs Illustrating the General Use of the Whole Equipment.

Plate No. 1, Fig. **6**, shows the accuracy of reproduction and recording of the equipment, when the generator was arranged to give pulses of from 7 to 14 i.p.s. and 63 per cent. to 70 per cent. in steps of 1 i.p.s., and with 3 pulses at 67 per cent., 7,10 and 14 i.p.s. No. 2 represents the same generator pulses, with the insertion between the generator and measuring unit, of a typical impulse repetition link. This link consisted of a battery dialling relay set, auto/auto relay set, and final selector A relay, with maximum permissible junction lengths between each item. It will be noticed that the distortion at 14 i.p.s. is very marked—the pulses being altered from 63 per cent. to 40 per cent. break.

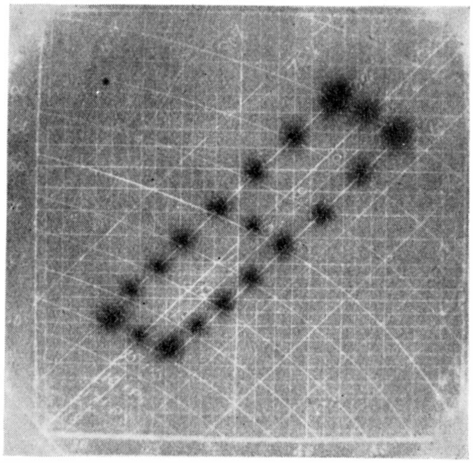
The definition of the spots is poorer than usual, due to the use of a cathode ray tube which was nearing the end of its life. A life of 1,000 working hours can usually be expected.

Possible Development as an Automatic Routiner for Impulse Repeating Equipment.

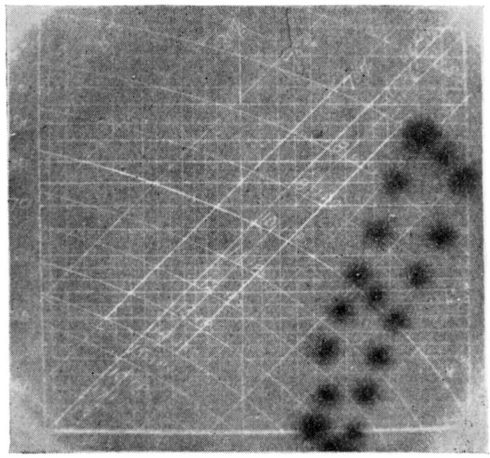
The functioning of the apparatus could be made entirely automatic by utilising the deflection voltages applied to the cathode-ray tube to operate alarms when certain limits are exceeded. Circuits for assessing the percentage and/or speed of the distorted impulses, operative on each impulse, have been formulated. In effect it is possible to define any permissible target area in terms of maximum and minimum speeds and percentages, to test apparatus with cyclic trains of impulses chosen in terms of the expected performance of the apparatus, and to indicate automatically which type of input impulse causes the output to exceed the defined area.

Use of the Equipment in the Field.

An equipment of this type has been constructed and installed at London Trunk Exchange, where a considerable number of dials in use on switchboard positions has been tested. Interesting results have been obtained in that a number of dials have been found to have one or two pulses which lie outside the normal range of 63 per cent. to 70 per cent. break. As indicated, this is only one of the many applications of which the equipment is capable.



1. *Normal Generated Target.* (7–14 *I.P.S.*, 63%–70% *Break.*)



2. *Generated target for* 1 *as received on Final Selector A Relay. Conditions were Battery Dialling Relay Set, Auto/Auto Relay Set, Final Selector—with maximum junction lengths.*

FIG. 6.—OSCILLOGRAMS SHOWING THE MEASURING EQUIPMENT USED IN CONJUNCTION WITH AN IMPULSE GENERATOR.

Franking (Postage Meter) Machines.

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Postage franking machines are of great value to business concerns, as they enable the purchase and fixing of stamps to be eliminated. The author describes the types of machines which the Post Office has approved for use in this country.

Introduction.

THE employment of the franked impression instead of the postage stamp by large users of the post has grown rapidly since the introduction of the system in this country in 1922, and more especially during the past few years. The principle is much older, however, since a machine which printed and recorded the necessary postage value on letters was produced in New Zealand as long ago as 1903. This type of machine, although modified in many ways to meet the requirements of the British Post Office, is still in use in this country, but is now regarded as obsolescent.

America was the next country to realise the potentialities of the system, which was introduced there in 1920, Germany and Great Britain following suit in 1922. Since that time the machines have been improved in range and reliability, and there are now in use in Great Britain approximately 7,500 franking machines of varying types. For the year 1938/39 the proportion of postal revenue accruing from franking machines was approximately 8 per cent. of a total of nearly £46 millions.

When it is realised that some large users of the post expend upwards of £250 weekly on postage, one advantage of the franking machine, so far as the public is concerned, becomes obvious, since the time and labour involved in affixing adhesive postage stamps to this value can be imagined. An additional advantage is that the franked impression is not negotiable, and pilfering of stamps, where postage is dealt with on a petty cash basis, is eliminated, as is also the need for stamp perforation, a system still in use by some concerns.

The Post Office is, of course, cognisant of the various advantages of the system to the public. Collection of correspondence from pillar boxes is also obviated as the licensee is required, as a condition of the license, to hand in franked correspondence, ready faced and bundled, at a prescribed posting office, where it can be passed direct to the primary sorting position, the cancellation of franked impressions by a stamp cancelling machine being unnecessary. The necessity, however, for a strict accounting system to be maintained to ensure safety of revenue, and for frequent checks of various kinds being made, largely outweighs this, and any other advantage to the Post Office, such as saving in printing costs and storage charges necessary for adhesive stamps.

For those who are not familiar with the system, the functions of the franking machine are set out as follows.

The machine must print :—

(1) The postage value, shown in a frank of approved design and colour ;

(2) An index number indicating the office of origin ;

(3) An officially approved postmark of the town, together with the date.

At the same time the recording mechanism must maintain an accurate record of postage used. The user is also permitted to use an advertising slogan of limited dimensions, which is printed simultaneously with the frank and postmark. For packets or other bulky parcels which cannot be franked direct by the machine, franked adhesive labels of approved design, and exhibiting the users name and address may be used. Franked impressions may also be used to denote the amount of telegraph and customs charges and certain other fees, but as this article is primarily intended to describe the machines from a technical standpoint, it is not proposed to include details of these facilities.

There are two firms in this country whose franking machines of different types have been officially approved for use. These are Messrs. The Universal Postal Frankers, Ltd., and Messrs. Roneo-Neopost, Ltd. These companies have entered into a bond, under the terms of which the British Post Office is indemnified against losses of revenue due to faulty meters, or to fraudulent usage. Fortunately, discrepancies which come to light during close checks maintained by the Post Office can usually be satisfactorily adjusted, and so far there has been no instance in which either company has been called upon to fulfil the conditions of the bond.

Franking machines are sold direct to the licensees. The meters for Pitney-Bowes machines, however, which are separate from the machine proper, are issued on a rental basis. The Post Office is not concerned in any way with prices or rental arrangements. The franking dies always remain the property of the manufacturers, who undertake to recover them and otherwise take responsibility for safe custody if a machine is for any reason surrendered or put out of use. Maintenance and regular servicing of the machines is carried out by the manufacturers, by arrangement with the users, and the manufacturers are required to forward a periodical certificate of good condition to the Post Office, in respect of each machine.

All new models must be approved in principle and in detail by the Engineering Department in conjunction with the Postal Services Department of the Post Office. In addition, rigorous tests are carried out to ensure that :—

(1) The machine and especially its recording mechanism is mechanically robust and likely to give reasonably fault-free service over a number of years.

(2) The recording mechanism and sealing arrangements are fool and tamper proof, and such as to minimise the possibility of fraudulent usage.

It is also desirable that the " setting " of the machines, where necessary, and subsequent re-sealing can easily be carried out by non-technical officers.

Before a new machine can be put into service the Postmaster-General issues a license which sets out fully the conditions under which franked impressions may be used for postage, telegraph and other prepaid charges, and which also contains complete details regarding the machine in respect of which it is issued. These are the number and type of the machine or meter, description of postmark, setting unit, value selections, etc. The prescribed setting office may or may not be the Post Office at which franked postage matter is handed in.

Each machine is provided by the manufacturers with two record cards or books, containing full particulars of the machine, license number, etc., and in which full details of all credit purchase transactions, and meter readings are entered at the setting office. One card is held at the setting office, and the other by the licensee.

Accounting Methods.

A "unit " system has been adopted for accounting, and for credit prepayments. The unit varies, but is generally one halfpenny. On certain machines, described later, the unit value is one shilling. A pre-payment of say £10 thus entitles the user of a machine to credit amounting to 4,800 units, or 200 units where the machine has a unit value of one shilling. The unit system enables decimal meters to be used and avoids the difficulties which arise due to sterling being non-decimal. The New Zealand machine already mentioned actually registers in sterling, but such a machine, if required for use in other countries, especially those with decimal currency, would need gearing alterations. The multi-value machine, which is described in some detail later, records in shillings, pence and halfpence. The unit is one shilling, however, and for setting purposes the meters are arranged in the same way as those whose unit is one halfpenny, i.e., the shillings part of the meter having units, tens, hundreds and thousands wheels. This machine, if required for use in a decimal currency system, would, of course, require alteration of the pence and halfpence counter gearing. It will be appreciated that the unit system enables the majority of machines to be used in any country, irrespective of the nature of currency in use, since the only alteration required would be the actual unit value and frank selection designations.

Machines are usually arranged to print a selection of franks, subject to a specified maximum value dependent on the type of meter fitted. Where the " Veeder " type counter is employed it has been found that this is unreliable if the maximum number of units registered per operation exceeds 25. Thus on machines fitted with " Veeder " or cyclometer type counters, and having a unit value of ½d. either a single value or a selection of 2, 3 or 6 values may be made available, the lowest and highest being ½d. and 1s. respectively, and the intermediate values being any multiple of ½d. The machines are also arranged so that should a value higher than the maximum be required, a cover or label may be impressed with two or three franks as required giving the requisite total value. If the maximum value required is higher than one shilling, with a unit value of ½d., machines employing a different type of counter are used.

When a new machine has been licensed, the prospective user must present it at the setting office, where credit is purchased, and, if necessary, the meter of the machine set accordingly. The licensee may then frank correspondence covers and parcel labels on his own premises until credit is exhausted, when a further prepayment must be made. He must also prepare, daily, and tender with the final consignment of franked post, a slip known as a " Posting Docket," on which details of final meter readings are entered, together with the licensee's name and machine number. This is a condition under which the licence is issued, and this form must be tendered whether the machine is used or not. The dockets are kept at the setting office and prove of the greatest use in tracing any discrepancies which may arise.

There are, broadly speaking, two types of machine, i.e., those with single counters or meters, and those with two. In the first the single meter simply registers the number of units used by the machine, and when credit is exhausted, the meter reading having reached a predetermined figure, the licensee is required to take the machine to the setting office for renewal of credit. When a new machine of the single meter type is first presented the counter shows cyphers only, i.e., 000,000. Payment of, say, £20 entitles the licensee to 9,600 units, and to use the machine until the counter reads 009,600. On renewal of credit for the same amount, the machine may be used until the counter reading reaches 019,200, and so on.

Machines of this type have the advantage of simplicity, and setting and sealing of the meters on renewal of credit is unnecessary. Should a meter fault develop, however, there is no check on possible discrepancies, other than average daily usage as computed from the daily posting dockets. It is of assistance if the licensee maintains an independent posting record. Practically all users of franking machines, and therefore comparatively large users of the post, are reputable concerns, and it is fortunately seldom that a satisfactory settlement cannot be reached.

With those machines fitted with two meters, or counters, one is known as the " credit " meter or sometimes the " descending register," and the second is called the " totalisator " or " ascending register." The meters are geared to work in unison after credit has been set up and the meters sealed. Two-meter machines are invariably arranged to lock automatically to prevent further operation when credit is exhausted. This locking point varies somewhat, but on the Universal " Midget," the machine " locks off " after the impression which reduces the remaining credit to less than 50 units. For instance, if the credit meter reads 00052, and a frank for a value of 6d. is impressed, 12 units are deducted leaving the credit figure at 00040, at which the machine locks.

The reason for this may not appear clear, and is explained as follows: if the machine were arranged to lock when credit was reduced to zero the final reading, if the meter stood at, say, 00002, would be 00002–12 units, which would give a final reading of 99990. This figure is, of course, not a true indication of remaining credit, which has, in fact, been overspent. Further, when credit is renewed there is the tendency to add the number of units paid for to the existing credit meter reading. If, for instance, 2,400 units are purchased the total would be 99990 + 2400 = (1)02390. This is, of course, incorrect, apart from the fact that the meter cannot in most machines accommodate more than 5 digits, and the sixth figure must be dropped. It is principally to obviate possible confusion in accounting that meters are arranged to lock at a figure sufficiently high to prevent the final reading falling below zero. By this means, also, a small amount of credit is kept in hand when the machine locks.

On the multi-value machine, the maximum impression of which is 29s. 11½d., the meters are arranged to lock the machine immediately credit falls below this maximum value. Thus, if the credit meter stands at 30s. and a ½d. frank is used the meter will lock at 29s. 11½d. If, on the other hand, a frank for the maximum value is used, the machine will lock at ½d., the final reading thus never falling below zero.

The principal advantage of the two meter locking machine is that safety of revenue does not depend on the reliability of a single meter. It is extremely unlikely that both meters will develop a fault simultaneously. If either meter fails to record correctly, the fact becomes immediately obvious when the two readings are totalled and compared with the total figure obtained at the last setting of the machine. Daily usage, calculated separately for each meter from the figures given on daily posting dockets, enables the faulty meter to be detected.

With this type of machine the locking feature renders it imperative for fresh credit to be purchased before the machine can again be used. When setting of fresh credit has been carried out, the meter door has to be closed and sealed with wire and a lead seal, special sealing pliers which impress the code letter of the setting office on the seal, being provided for use by setting officers. This is, of course, unnecessary on single meter, non-locking machines. Access to the meters cannot be obtained without breaking this seal. In addition the covers of all machines are sealed by the manufacturers to ensure that the cover cannot be removed and the interior mechanism tampered with, without this fact becoming apparent.

The Universal Midget Machine.

Fig. **1** shows, diagramatically, the arrangement of the two meters, as fitted to the Universal "Midget" machine.

The drive to the credit meter and totalisator is through a common pinion which is in turn actuated by a mechanism similar to that shown in Fig. **3**. This common drive ensures that the meters, while operating in unison, shall count in reverse directions, the totalisator moving up, and the credit meter down. The drive is received on the units wheel of the credit

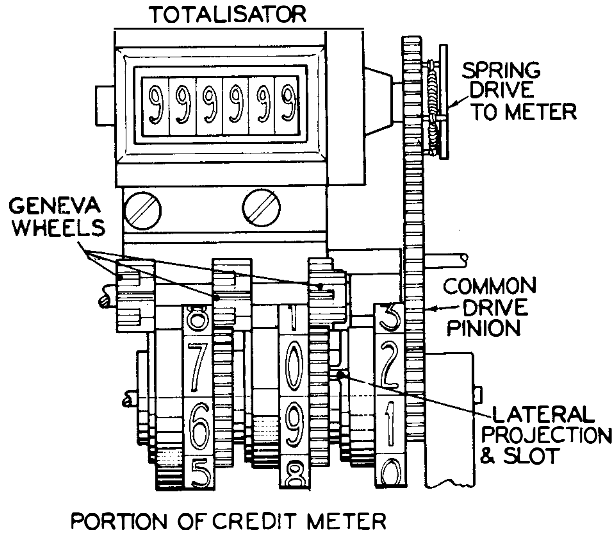


Fig. **1**.—Arrangement of Meters and Drive of "Midget" Machine.

meter, the necessary operation of the tens, hundreds, thousands and ten thousands wheels being carried out as follows: at the rear of the credit meter is a shaft which carries a series of small free pinions called geneva wheels, which engage with the teeth of the credit meter wheels. The geneva wheels have, on one side, a portion of alternate teeth cut away. Each credit wheel flange is provided with a lateral projection in which is cut a slot of sufficient width to take the teeth of a geneva pinion. When the units wheel reaches zero this projection engages with a cut-away tooth on the geneva. At the next operation, when the credit wheel turns to 9, the geneva is rotated, carrying with it the tens wheel, which turns down one division, the projection on the units wheel also clearing the geneva pinion. This "carry-over" or "transfer" as the operation is called takes place in a similar manner when the hundreds, thousands and ten thousands wheels are required to turn down to the next figure as credit falls. The totalisator meter of the "Midget" machine is of the "Veeder" type, and is driven direct, as shown, by the common drive pinion, the turnover mechanism being internal.

The locking mechanism of a "Midget" machine is shown in Fig. **2**. This is typical of most types, which, however, vary considerably in detail and construction, but embody the same principles. Beneath the credit meter is the spring-loaded "locking bar." This, when the meter has been "set," is held in position against the action of its spring by four projections on the locking triggers which engage with four slots in the locking bar. The locking triggers are carried on a shaft below, and slightly to the rear of the meter wheels. Each trigger is separately spring-loaded, and bears normally on the flange of the relative credit meter wheel. A cam is provided on the flange of the ten thousands, thousands, hundreds and tens wheels. As credit is expended, each of the first three wheels, in the order given, turns down to zero. In this position the cam engages with the trigger and forces the projection out of its slot in the locking bar. The spacing of the slots and triggers is arranged so that locking takes place

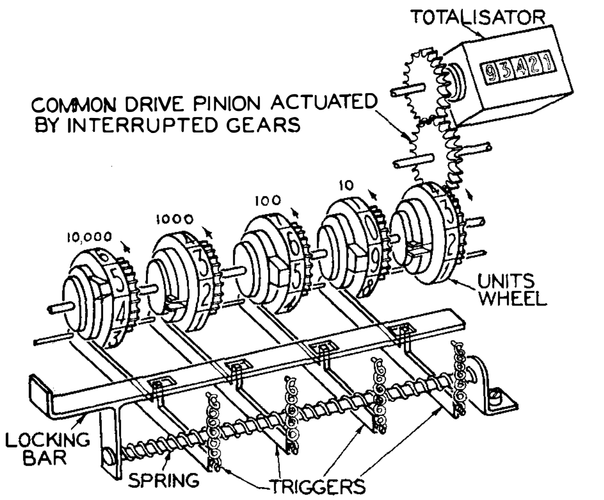


FIG. 2.—LOCKING MECHANISM OF " MIDGET " MACHINE.

successively from the highest digit downwards. The locking bar, as each of the three wheels reaches zero, is then forced slightly to the left until arrested by the trigger of the next wheel. The condition is then reached, when the first three wheels are reading zero, that the locking bar is held only by the trigger of the tens wheel. The Midget machine locks, as already explained, when credit falls below 50, and the cam is therefore arranged so that the trigger is engaged when the tens wheel turns to 4; that is, when the final credit figure falls to 00049, 00048, etc. When the remaining trigger is thus engaged the locking bar " shoots " under the action of its spring. By an arrangement of levers, actuated by the movement of the locking bar, the operating handle of the machine is effectively locked, preventing further operation. On renewal of credit the opening of the meter door to its fullest extent by the setting officer automatically unlocks the machine, forcing the locking bar back to its position relative to the triggers. The setting of the wheels by hand to the required figure removes the cams from zero position and allows the triggers to enter their respective slots.

The Midget machine gives a selection of 5 values, from ½d. to 1s. maximum, with the ½d. unit, with any desired intermediate values. Value selection is aranged in a similar manner to that shown in Fig. **3**, by means of sliding interrupted gears. When credit is exhausted and the machine is locked and is presented for renewal of credit, the opening of the meter door releases the lock, as already described. Inside the meter door, between the credit and totalisator meters is a setting lever, which, when lifted by the setting officer, raises the geneva pinions out of engagement with the teeth of the credit wheels. This allows the setting officer to move the tens, hundreds, thousands and ten thousands wheels to the desired setting. The units wheel cannot be moved, as this remains in engagement with the common driving pinion. On completion of setting the setting bar is replaced, the genevas dropping back into place on the credit wheels.

This machine is a development of the now obsolete " H " machine, and is very similar except that it is more compact. The " H " machine locks when credit falls below 100 units. In addition to franking and postmarking, the " H " machine also moistens and seals the flaps of covers, a water reservoir and moistened brushes being incorporated for this purpose.

Single Meter Machines.

Fig. **3** shows the simple mechanism of a single-meter machine. The value selector lever moves the interrupted gear assembly along the main shaft on a sliding key-way to bring the relative gear opposite the gear of the Veeder type counter. Operation of

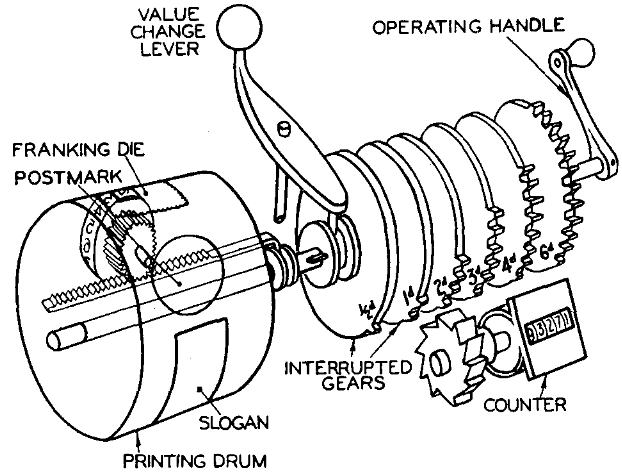


FIG. 3.—VALUE SELECTION AND COUNTER DRIVE OF SINGLE COUNTER, NON-LOCKING MACHINE.

the machine handle then rotates the printing drum, on which are carried the franking and postmarking dies, and, if used, the slogan die. The actual printing value of the frank die is changed during the value selecting operation by a rack carried by the interrupted gear assembly. The value figures on the die itself are engraved on a drum fixed to a pinion which engages with the value change rack. Movement of the value change lever rotates this drum to the position in which the relative value face is flush with the surface of the franking die.

Various models of " Neopost " and Universal machines are now in use. With one exception, that of a 12 value machine, which, however, is not yet in production, " Neopost " machines are of the single meter, non-locking type.

The " Neopost " machine, as illustrated in Fig. **4**, is available in a range giving either single values or 2, 3 or 6 value selections. The maximum denomination, where the Veeder type counter is employed is, as mentioned previously, limited to 25 times unit value. Should the licensee require a machine to frank higher values than this maximum a different counter is employed. This is of the flat disc type similar in appearance to an electricity meter, having flat figure dials. This counter has been approved for recording up to 100 units per operation, and is known, therefore, as the " 100 " type counter. The maximum franking value obtainable is, with the ½d. unit, 4s. 2d., but the values usually range between ½d. minimum and 4s.

An interesting feature of this meter is the method of operation by the interrupted gears. The arrange-

Fig. 4.—Neopost 6-Value Machine with "25" Type Counter.

ment of these is also rather different from that already described, and the drive is taken by the counter on both the units and tens dial spindles. An impression of 4s. is equal to the expenditure of 96–½d. units. When the value selecting lever is placed in the appropriate position two interrupted gears are brought into position adjacent to the driving gears of the units and tens dial spindles. On operation of the machine handle, 6 impulses are given to the units spindle which record's and carries over, if necessary, on the tens spindle. When this carry-over is complete, the tens spindle receives 9 impulses from the other interrupted gear, and the meter thus records 96 units. If the machine is provided with a 2s. 6d. frank value, the interrupted gear is arranged to give three impulses to the tens wheel, and so on. By this the necessity for the units wheel taking the whole of the drive is obviated and wear is distributed more evenly over the driving parts of the counter.

The New Zealand Machine.

The New Zealand machine already referred to as being the first of its type, is practically obsolete, and it is not proposed to deal with this in any detail. It is interesting to note, however, that it is the only machine in use in this country that, in addition to recording in sterling employs a reciprocating printing movement. It provides six value selections, the maximum being 25 times unit value. The meter portion, on which credit is set, is detachable from the machine proper, which is automatically rendered inoperative during its absence.

Pitney-Bowes Machines.

A series of Pitney-Bowes machines and meters, manufactured by Universal Postal Frankers, Ltd., under an American licence, is also supplied, and covers the following ranges :—

Single Value (locking meter).
Single Value (non-locking meter).
6 Value (locking meter).

The meters are detachable and are designed for use on a power driven machine similar in appearance to the stamp cancelling machines used by the British Post Office. This machine is capable of franking, postmarking, moistening and gumming mixed mail at the rate of approximately 375 items per minute, and it will be appreciated that its use tends to be confined for this reason, and by reason of its cost, to the very large users of the post.

Until the comparatively recent introduction of the 6 value meter, it was usual for a licensee to have one machine, and also one or more single value meters of different denominations, as required. The detachable meters are presented separately for renewal of credit as with the New Zealand machine. The meter portion comprises the franking and postmarking dies, and the two meters and locking mechanism, the credit meter being arranged and set much in the same way as the Midget machine. The credit meter of the 6 value machine is designed to lock at the first impression which brings the reading below 100, whereas the single value meters lock at zero, the unit value being the value of the single impressions available.

The non-locking Pitney-Bowes meter has a single meter only, which records total usage, as with the "Neopost" single meter machines.

Universal Multi-Value Machines.

The most interesting, from a mechanical point of view, is the Universal "Multi-Value" range of machines. Some of the principles employed are very ingenious. The range comprises 3 models, which are

(1) Junior Multi-Value, giving value selections from . . ½d. to 11½d.
(2) "3 Bank" Multi-Value, giving value selections from . . . . . . ½d. to 9s. 11½d.
(3) Multi-Value, giving value selections from . . ½d. to 29s. 11½d.

The general appearance of the machines is shown in Fig. 5, the three models having the same frame

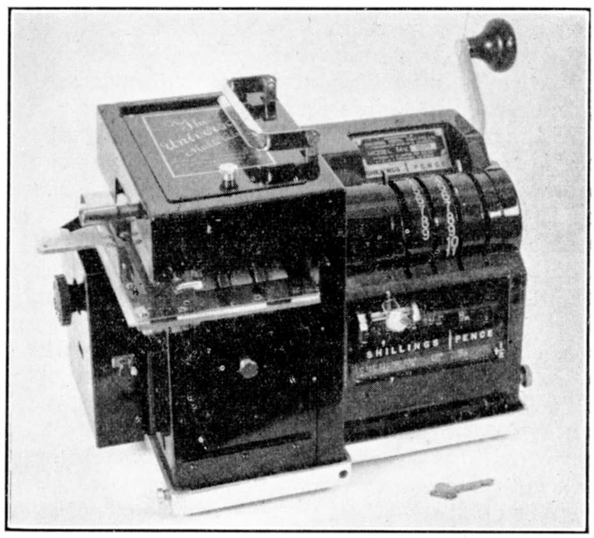


Fig. 5.—Universal Multi-Value Machine.

size. The locking meter mechanism employed is similar in principle to that of the Midget machine and both ascending and descending meters are geared to work in unison.

On the multi-value model, the values available are from $\frac{1}{2}$d. to 29s. 11$\frac{1}{2}$d. in $\frac{1}{2}$d. steps, amounting to a selection of some **719** different values. This wide range is obtained by a value selector system employing what is known as a " ducking " tooth principle. This is illustrated in Fig. **6.** Each digit of the value

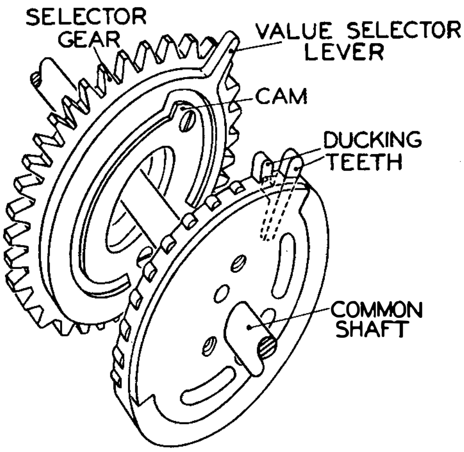


FIG. **6.**—" DUCKING " TOOTH SELECTOR MECHANISM.

selection corresponds to a separate figure on the franking die, there being thus, for a value of, say, 29s. 11$\frac{1}{2}$d., a row of four-digit selectors, i.e., 2, 9, 11 and $\frac{1}{2}$d., the value selecting mechanisms being mounted on a common shaft. The selector lever actuates a cam, which engages internally with a series of steel teeth. When the lever is moved to the required position, the cam causes certain teeth to be projected and form an interrupted gear. That is to say, if the value selected is for an impression of 18s. 6$\frac{1}{2}$d., the four selector levers are set to cause, 1, 8, 6 and 1 teeth to be projected from the shillings tens and units discs and pence and halfpence discs respectively.

The meter gearing and transfer arrangements are rather more complex than those of the Midget machine, as the pence and halfpence wheels must be geared to translate pence into shillings and complete the carry over to the units wheel when necessary. In addition, when the value selected includes tens of shillings, these are transferred direct to the tens wheel of the meters, which in turn completes the carry over to the hundreds wheel when necessary.

When the machine is presented for renewal of credit the action of unsealing and opening the meter door automatically unlocks the meter wheels, and in addition disengages the geneva transfer pinions, allowing the wheels of the descending register, or credit meter, to be set to the required position by hand.

The method by which the printing figures on the

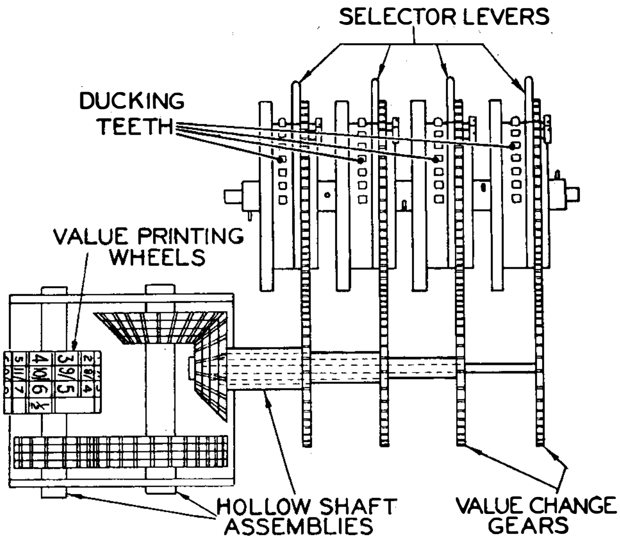


FIG. **7.**—VALUE CHANGE MECHANISM.

die are changed simultaneously with the selection of values is shown in Fig. **7.** Each value selector unit gear meshes with another gear mounted on the end of a hollow shaft. On the multi-value model there are four such shafts, one inside the other. Movement of the selector gears during value selection is transmitted by the hollow shafts to a nest of bevel gears connected with the four figure printing wheels, which are rotated thereby to the correct position relative to the die face.

The " Junior " and "**3** Bank" models differ from the Multi-Value model only in that, in the first machine, the tens and units shillings selector, and in the second, the tens selector, are absent. The machines, however, work in exactly the same way.

An additional feature of these models is the trip mechanism, which prevents wastage of impressions due to inadvertent movement of the operating handle, which must complete its cycle. The trip is operated by the insertion of correspondence in the printing aperture, the depression of the trip tongue freeing the operating handle. In most other machines a thumb trip lever is provided, which, while preventing accidental operation, does not guard against wilful misuse by irresponsible persons.

It should be explained that the majority of " Neopost " and " Universal " machines can be adapted for power drive, which scheme is often adopted by licencees whose posts are fairly heavy but who do not consider the cost of a machine such as the Pitney-Bowes type justified.

Acknowledgement

Finally, the author would like to express his thanks to Messrs. Roneo Neopost, Ltd., and Messrs. Universal Postal Frankers, Ltd., for permission to publish details of their products, and for other useful information furnished.

Apparatus for the Measurement of Insertion Phase Shift at Radio Frequencies

U.D.C. 621.317.363.029.6 R. F. J. JARVIS, Ph.D., and E. F. S. CLARKE, B.Sc.

The design and development of apparatus giving a direct visual indication of insertion phase shift at radio frequencies is described. The theory of the method used and of the principle of operation of the rotary phasemeter are given in detail.

Introduction.

In the development of television apparatus, particularly that required for line transmission of television signals, it soon became evident that apparatus capable of measuring phase shift over a wide frequency range would be of great assistance.

Phase measuring apparatus, in which the phase comparison between two voltages of high frequency is made at the incoming frequency, cannot readily be designed to give a direct reading of phase difference on a meter. If the two points, between which the phase difference is to be determined, are connected to two identical frequency changers operated from a common beating oscillator, the phase difference between the two difference frequency outputs is the same as that between the two points, and the phase comparison can then be made at a constant difference frequency. Valve circuits have been employed in the past to make this comparison, but calibration curves are generally needed, and switching arrangements to determine in which quadrant the phase angle lies. Mr. A. J. Gill suggested that these could be avoided by using a difference frequency sufficiently low to enable a rotary phasemeter to be employed to measure the phase difference at that frequency. As the reading of this type of meter is not independent of frequency, it was thought desirable to obtain a meter operating on as high a frequency as possible, so that absolute frequency changes in the signal or beating oscillators would be accompanied by the smallest possible percentage change in difference frequency. The manufacturers of the rotary phasemeter thought that the highest practical frequency for the operation of an instrument of this type was 750 c/s.

Considerable difficulties were encountered both by the manufacturers of the phasemeter and by the Post Office in the development of the apparatus, although these have now largely been overcome. The apparatus described is intended only for insertion phase measurement, i.e. the measurement of phase difference between two points both of which can be connected to the apparatus. It can therefore only be used on line measurements when a loop circuit can be formed.

Outline of the Apparatus and Method of Operation.

The principle of the operation of the apparatus will be understood by referring to Fig. **1**. The oscillator supplies a voltage at the desired frequency which is applied to the frequency changer No. 1 and to the input terminals of the apparatus under test. The voltage appearing at the output terminals of the latter is applied to the frequency changer No. 2. The beating oscillator injects a voltage at a suitable frequency into both frequency changers, and the output voltages, at the difference frequency, are

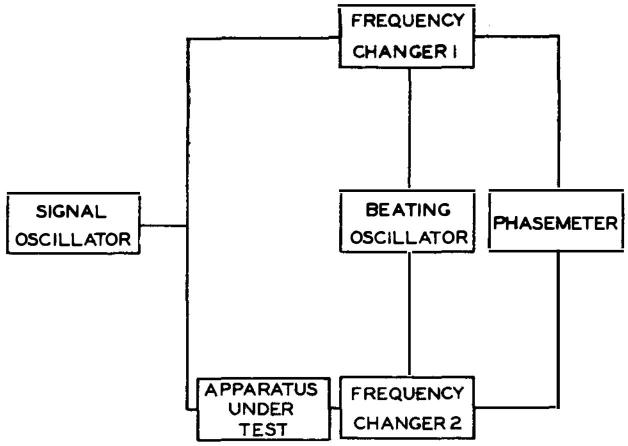


FIG. 1.—SIMPLIFIED DIAGRAM OF APPARATUS.

applied to the phasemeter which gives a visual indication of the phase difference between them. This difference is equal to the difference in phase between the signal frequency voltages applied to the two frequency changers.

Proof of the latter statement is given in Appendix 1, where it is shown that if the voltage applied to the frequency changer 1 is $V_1 \sin \omega t$, and that applied to the frequency changer 2 is $V_2 \sin (\omega t + \phi)$, i.e. leading the former voltage by an angle ϕ, and the voltage applied to each from the beating oscillator is $V_3 \sin \omega_1 t$, then the respective difference frequency output voltages will be of the forms

$$\frac{1}{2} K_1 V_1 V_3 \cos \pm (\omega - \omega_1) t$$

and

$$\frac{1}{2} K_2 V_2 V_3 \cos \pm \{(\omega - \omega_1) t + \phi\}$$

the positive signs corresponding to $\omega_1 < \omega$, and the negative signs corresponding to $\omega_1 > \omega$.

When the beat oscillator frequency is less than the signal frequency the phase difference between the difference frequency output voltages is therefore equal and opposite to that obtained with a beat oscillator frequency greater than the signal frequency. This fact has been found of value, when operating the apparatus to be described, as a means of improving its accuracy.

A schematic diagram of the complete apparatus is shown in Fig. **2**. The oscillator feeds equal voltages of the same phase into the circuit under test and into a buffer amplifier which precedes one of the frequency changers. In the anode circuit of this frequency changer valve are a 750 c/s band-pass filter and an attenuator, the output from which is amplified to 110 V R.M.S. to feed the rotor coil circuit of the phasemeter. In the anode of the first amplifying

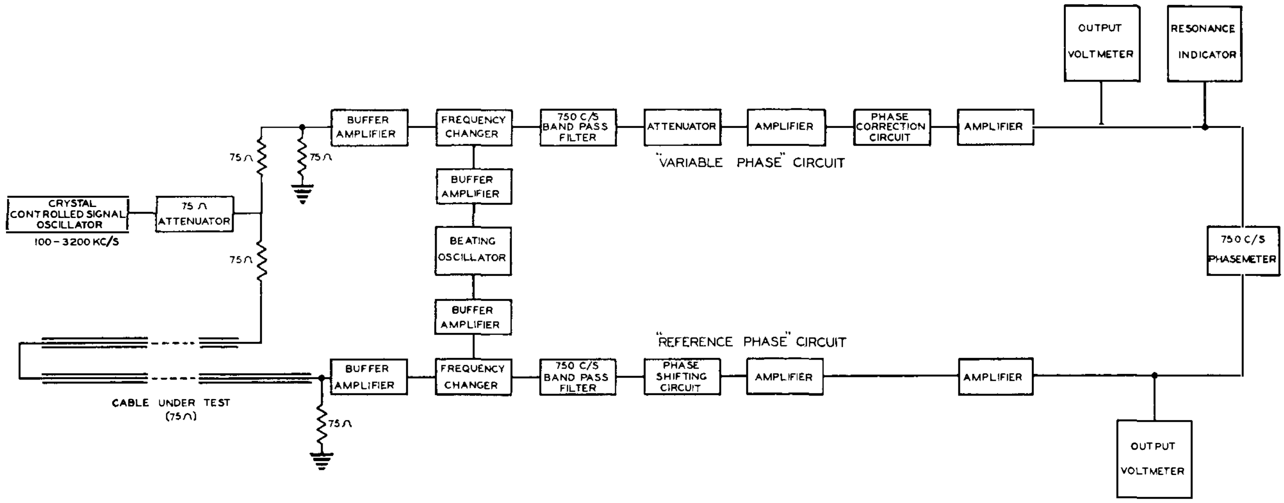


FIG. 2.—APPARATUS FOR MEASURING INSERTION PHASE SHIFT.

valve is included a resonant circuit designed to compensate the phase angle/frequency characteristic of the stator coils of the phasemeter.

The output side of the circuit under test is connected to a similar buffer stage and frequency changer. There is no attenuator in the output circuit of this frequency changer, but following the filter is a capacitance and variable resistance network to introduce a variable phase shift. This is used to equalise the phase shifts in each frequency changer and its associated filters, amplifiers and wiring.

The beating oscillator is designed to be very stable, for reasons explained later.

The Rotary Phasemeter.

As the apparatus is, to a large extent, built round the phasemeter, it is proposed to describe this instrument and its associated components in some detail.

The rotary phasemeter employed is a modified version of a type of rotary synchroscope used on power switchboards to synchronise 50 c/s alternators. A simplified version of the circuit is shown pictorially in Fig. **3**. Coils A and A_1 are air core coils and are

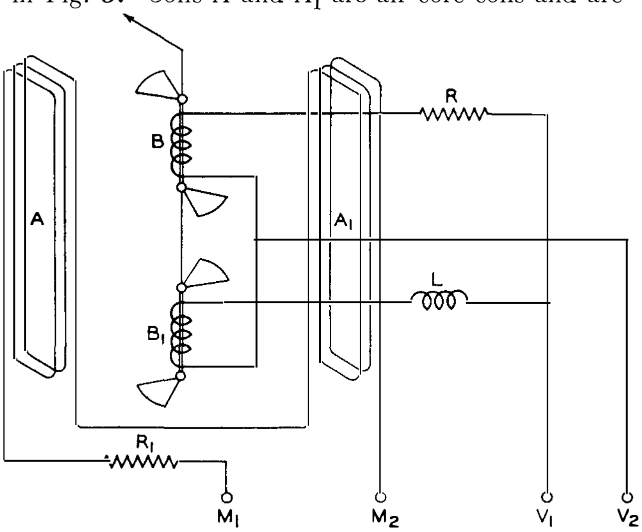


FIG. **3**.—ROTARY PHASEMETER. SIMPLIFIED CIRCUIT DIAGRAM.

connected in series with a resistance R_1 across one pair of terminals The value of R_1 is made high compared with the reactance of the coils so that the field produced by A and A_1 will be approximately in phase with the voltage applied to the terminals M_1, M_2. The coils are fixed together with only a narrow gap between them so that in this region an approximately uniform field is produced.

Two smaller coils B and B_1 are fixed inside A and A_1 with their common axis passing through the centre of the gap and perpendicular to the axis of A and A_1. These two coils are connected, in series with a resistance R and inductance L respectively, across the other two terminals V_1 and V_2. It will be seen that, provided R and L are large compared with the impedances of B and B_1, the current and field in B will be in phase with the voltage across V_1 and V_2, whereas the field in B_1 will lag behind the voltage by $\pi/2$ radians.

The spindle of the instrument passes through the axis of B and B_1 and to it are fixed four vanes of magnetic material and of quadrant shape. They are arranged in pairs diametrically opposed on the spindle at either end of each coil, as shown in Fig. **3**, there being a relative angular displacement of $\pi/2$ radians between the two pairs. The material of the spindle itself is non-magnetic, but there are two sleeves of magnetic material placed over the spindle which connect the vanes of each pair. The magnetic vanes tend to produce a concentration of the radial flux in coils B and B_1 along the lines bisecting the vanes.

It is shown in Appendix 2 that if voltages V sin ωt and V sin $(\omega t + \phi)$ are applied to the terminals M_1 M_2 and V_1 V_2 respectively, the total torque on the spindle will be

$$k\,V^2 \sin(\theta - \phi)/2RR_1$$

where k is a constant of the instrument and θ is the deflection of the vanes. If this is plotted against θ for any value of ϕ it will give a sine curve which passes through zero at $\theta = \phi$ and $\theta = \phi \pm n\pi$. The slope of the curve at $\theta = \phi \pm n\pi$ will be positive when n is zero or even, and negative when n is odd. For practical purposes only the values of θ between 0 and

2π need be considered since the phasemeter registers only 0–360°. Suppose the torque is regarded as positive in a clockwise direction and that increasing angles are represented in the conventional manner by anti-clockwise rotation. Then at $\theta = \phi$ a small increase in the value of θ will result in a clockwise torque being exerted on the pointer and a decrease in θ will result in an anti-clockwise torque, so that in each case the torque tends to restore the original conditions of equilibrium and the reading $\theta = \phi$ is a stable condition. At $\theta = \phi + \pi$, however, an increase in θ will result in an anti-clockwise torque tending to increase θ still further so that this position is one of unstable equilibrium and may in practice be ignored. Thus there is no ambiguity in reading the correct value of θ. The two positions are shown in Fig. **4**, where the torque scale reading curve for

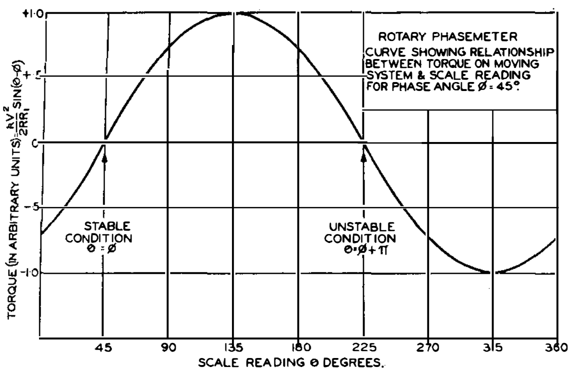


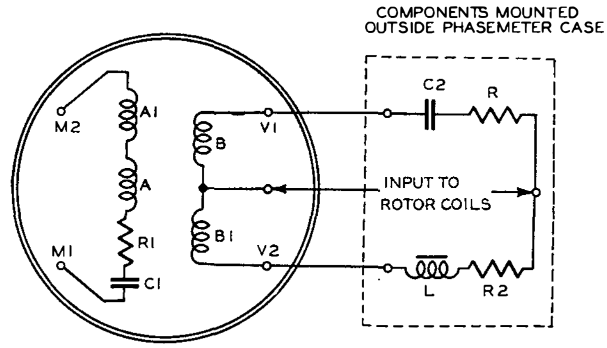
FIG. **4**.—TORQUE-SCALE READING CURVE.

$\phi = 45°$ is shown ; curves for other values of ϕ will, of course, be identical in form but displaced in a horizontal direction.

In deriving the above simple expression for the torque in the instrument various assumptions have been made, some of which are not fully justified in practice. It is assumed, for example, that the "stator" coils produce a uniform field in the gap between them, that the coils B and B_1 with their associated pairs of quadrants are electrically and magnetically similar, and there is no interaction either between the coils themselves or between the "stator" and "rotor" coil systems. It is also assumed that the impedance of coils B and B_1 is negligible in comparison with R and ωL, and that ideal conditions exist, such as perfection of mechanical balance of the moving system and absence of friction and external fields. Although these ideal conditions are not in fact attained, they are approached to such a degree that the above theory may be regarded as an approximate explanation of the operation of the instrument.

It has been found possible to obtain fairly good agreement between scale reading and phase angle by careful choice of the resistances and reactances placed in series with the coils B and B_1.

It was considered that a standard 50 c/s instrument was unsuitable for the purpose required owing to the very high degree of frequency stability which would be needed for two oscillators to maintain accurately a difference frequency of 50 c/s. Although very little information was available regarding the performance of such a phasemeter under conditions of varying frequency, it seemed obvious that a much higher working frequency was desirable, so that an absolute change in oscillator frequency would represent a smaller percentage change in difference frequency. Only one firm could be found which was prepared to undertake the development work involved and this firm was unable to produce an entirely satisfactory instrument. The phasemeter eventually supplied had to be considerably modified to meet requirements. The final circuit is shown in Fig. **5**.



	INDUCTANCE AT 1000 C/S	RESISTANCE D. C.	RESISTANCE AT 1000 C/S	CAPACITANCE AT 1000 C/S.
L	0·122 H	6·35 Ω	33·7 Ω	——
B	0·032 H	25·5 Ω	60 Ω	——
BI	0·032 H	24·6 Ω	66·5 Ω	——
A+AI (SERIES)	0·415 H	——	290 Ω	——
CI	——	——	——	0·10 μF.(APPROX)
C2	——	——	——	0·11 μF.
R	——	1642 Ω	——	——
RI	——	1197 Ω	——	——
R2	——	1436 Ω	——	——

FIG. **5**.—FINAL CIRCUIT ARRANGEMENT OF PHASEMETER.

The given component values were found by experiment to give the best results. It was found by calculation that the current in the inductive branch lags behind the applied voltage by about 25° and the current in the capacitance branch leads by about 45°. There is, therefore, a phase difference of about 70° between the currents flowing in B and B_1 which, although far from the theoretically correct angle of 90°, is considerably nearer than in the original circuit. The impedance of both branches has been raised but there still exists a difference of nearly 50 per cent. in their magnitudes. With the final circuit components the maximum error in the linear phase scale of the instrument was 4° at 750 c/s.

Calibration of the Phasemeter.

The calibration of the phasemeter was carried out by means of a specially designed and constructed 750 c/s 0–360° calibrating unit, the circuit diagram of which is shown in Fig. **6**. The variable phase output voltage is obtained from two of the four tapped resistance potential dividers $R_1 - R_4$ which form part of two constant resistance networks. By suitable choice of values for L and C, quadrature relationships exist between equal currents flowing in the four potential dividers, and by taking successive

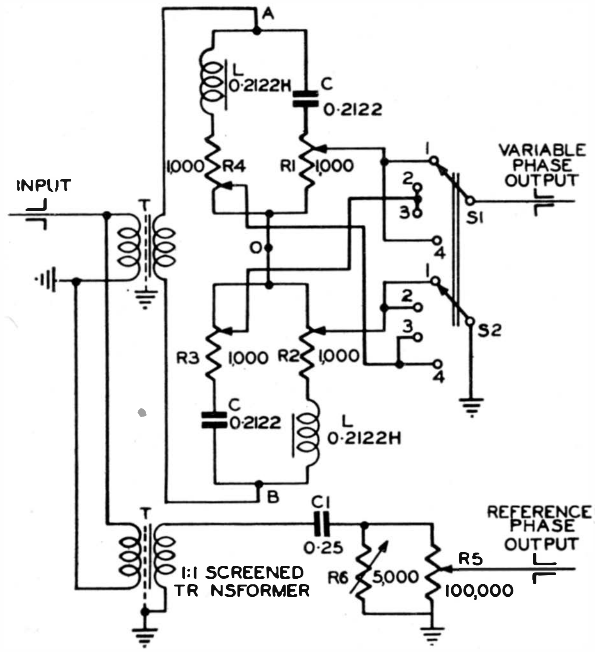


Fig. 6.—150 c/s Phasemeter Calibrating Unit.

pairs of potential dividers in turn a complete rotation of the output voltage vector is obtained. The potentiometer steps are arranged so that there is a 10° phase shift between adjacent positions on each switch.

S_1 and S_2 are ganged rotary switches for changing the quadrant of the output voltage vector. With these in position 1, R_1 at minimum and R_2 at maximum (the " maximum " setting being that nearest to the common point ' O ') the variable phase output voltage will lead the voltage across AB by 45°. In order that this position may be used as a zero or " reference " position, a " reference phase output " which can be preset to the same angle of lead is provided in the form of a separate simple resistance-capacitance network.

With S_1 and S_2 in the same position but with R_1 increased and R_2 correspondingly decreased, the output voltage vector is advanced by any required angle up to 90°, but the amplitude remains unchanged.

For the second quadrant S_1 and S_2 are set to position 2, which connects the moving contacts of R_2 and R_3 to the output terminals. The changeover is effected with both R_1 and R_3 at maximum, the common point for all four switches, this being the condition necessary for no change in phase or amplitude. The second quadrant is covered in the same way, R_2 being increased while R_3 is decreased, and so on through the third and fourth quadrants, each potentiometer setting being decreased in one quadrant and increased in the next.

The dials of the potentiometer switches are marked with the phase angles corresponding to each position. Although, as a result, there are two angles for each position, ambiguity is not possible since it is necessary to set two switches simultaneously.

When calibrating the phasemeter the two 750 c/s outputs from the calibrating unit were applied to the grids of the two buffer amplifiers preceding the frequency changers (see Fig. 2), the 75 ohm input resistances of these amplifiers being removed and the beating oscillator switched off. To ensure similarity of gain and phase shift in the frequency changer and amplifier stages, the two inputs were first connected in parallel and the gain and " zero angle " controls adjusted to give equal outputs and zero reading on the phasemeter. The " variable phase " and " reference phase " outputs of the calibrating unit were then connected to the appropriate frequency changer amplifier valves, the " variable phase " output being set to the zero position. The variable resistor and potential divider in the " reference phase " circuit were adjusted to give the same output as the " variable phase " circuit and zero reading on the phasemeter, and this setting was maintained throughout the calibration, its constancy being checked periodically by returning to the zero position on the " variable phase " output.

The phasemeter, with its cover removed, is shown in Fig. 7, the components associated with the rotor coil circuit having been removed outside the case of the phasemeter. This was done to prevent interaction with the stator coils. Two rectifier-type

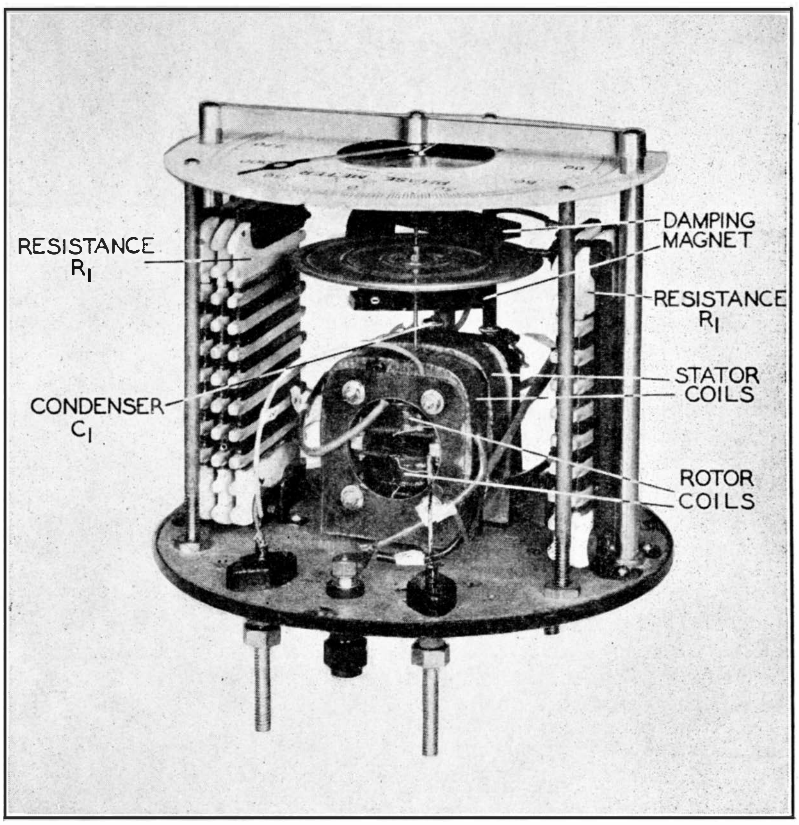


Fig. 7.—Phasemeter with Cover Removed.

voltmeters are connected permanently across the two inputs to the phasemeter, which requires 110 V (R.M.S.) at both inputs. These may be seen on the phasemeter panel in the photograph of the complete equipment, Fig. **8**. The third instrument on the panel is a resonance indicator, consisting of a 0 –1·5 voltmeter (rectifier type), which is connected across one of the phasemeter inputs.

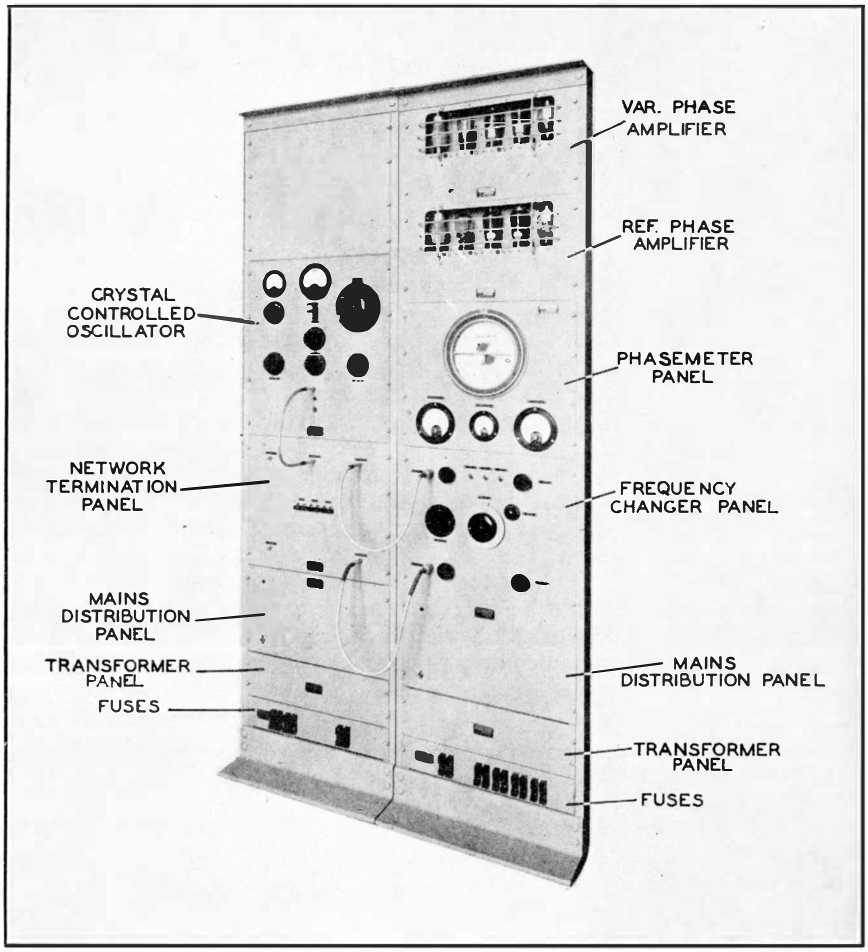


Fig. 8.—Rack Layout.

The Phasemeter Amplifiers.

The amplifiers used for feeding the two phasemeter circuits are commercial types rated at 15 watts output with an input of 30 mV. Three stages are used, the output stage consisting of two pentodes operating in push-pull with negative feed-back and supplying an output of 110V R.M.S. They are shown at the top of the right-hand rack in Fig. **8**. In their original form the frequency response was flat between 50 c/s and 5,000 c/s, but the gain at the low frequency end was later reduced by decreasing the values of the coupling condensers and grid leaks in order to reduce mains hum.

The Frequency Changer Panel.

The frequency changer panel includes the two octode "mixing" valves, each with two buffer stages, two 750 c/s band-pass filters, two amplifier stages, and a common beating oscillator. Following one frequency changer in what has been referred to as the "reference phase" circuit (the lower portion of Fig. **2**), a variable resistance-capacitance network is introduced between the filter and the amplifier stage to provide a manual adjustment of phase angle. In the upper "variable phase" circuit an attenuator is also inserted between the anode of the frequency changer and the amplifier to maintain equal voltages at the two phasemeter inputs when the inputs to the two frequency changing valves are different, as when measuring the insertion phase shift of a network which introduces loss. In the anode circuit of this amplifier is a series tuned circuit resonant at 750 c/s, with adjustable damping resistance, which is designed to compensate for the phase angle-frequency characteristic of the phasemeter coils. It has been found that by this means the phasemeter is made to give a reading which is constant within $\pm$ 1° for a change in frequency of $\pm$ 50 c/s. By means of the resonance indicator on the phasemeter panel a change in frequency of 10 c/s can be readily observed and corrected. An outline of the existing experimental circuit is shown in Fig. **9**, and the layout of the front panel is shown in Fig. **8**, immediately below the phasemeter panel.

The function of the buffer stages between the beating oscillator and the frequency changer valves is to avoid a common impedance in the oscillator grid-cathode paths of the latter. Although the control grid-oscillator grid and anode-oscillator grid capacitances are small in the type of valve employed they are not negligible. In the absence of buffer stages, a voltage at signal or difference frequency may be induced in one frequency changer circuit closely related in phase angle to that existing in the other frequency changer circuit. If the degree of coupling is sufficiently large an error is almost certain to be introduced in the phasemeter reading by this effect. The magnitude of the error will, however, depend upon the nature of the common impedance in the oscillator grid circuits, the signal and difference frequencies, the magnitude of the true phase angle between the received signals, and the relative amplitudes of these signals. Since the apparatus was to be used with differences in the input levels of at least 40 db. it was essential that the degree of coupling should be very low, and it was found that this could be satisfactorily achieved only by buffer stages. The buffer stages between the input sockets and the

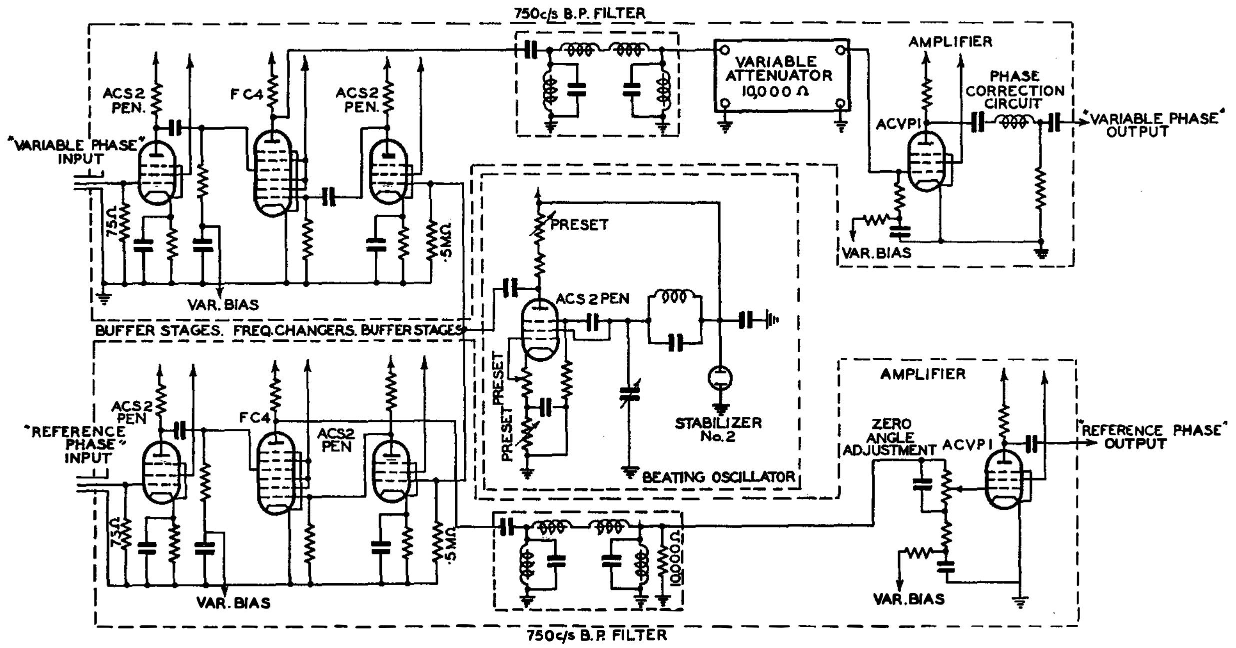


FIG. 9.—FREQUENCY CHANGER AND OSCILLATOR UNITS.

control grids of the frequency changers are even more important. Owing to the "induction" effect exhibited by octode frequency changer valves, a voltage at the beating oscillator frequency is produced on the control grid and this voltage may actually be greater than that of the incoming signal. When measuring the insertion phase shift of a circuit with zero loss or gain therefore, in the absence of buffer valves the voltage induced on one frequency changer grid will appear on the signal grid of the other with a phase change dependent upon the characteristic of the network. If the effect were reversible the net effect, assuming identical frequency changer valves, would appear to be that of changing the phase of the beating oscillator, there being no resultant change in the relative phase angle of the difference frequency outputs. Since, however, the network may not be symmetrical and may include one or more repeaters the effect may not be reversible. In this case, if intermodulation occurs between the signal and the unwanted beating oscillator voltage on the signal grid, a corresponding difference frequency component of spurious phase position will be produced and an error in phasemeter reading will result. The use of H.F. pentode buffer stages effectively eliminates errors arising from this cause.

In view of the fact that the phasemeter will read correctly only over a narrow band of frequencies the stability of the beating oscillator is a matter of primary importance. The short period stability must be such that during a measurement the change in frequency does not exceed $\pm$ 50 c/s or preferably the minimum change visible on the resonance indicator (about $\pm$ 5 c/s). The most likely cause of short period instability being supply mains variations, both H.T. and L.T. voltages are fully stabilised, and the stability is further improved by using a type of oscillator which is less susceptible than most to supply variations.

This oscillator employs a pentode valve operated in a circuit in which the valve exhibits a negative resistance characteristic. Although the principle of this circuit is not new, it is becoming increasingly popular in the U.S.A. under such names as the "Retarding Field" and "Transitron" oscillator. The circuit is somewhat similar to that of a dynatron in that the mean potential of the screen is higher than that of the anode and the control grid is maintained at a potential approximately equal to that of the cathode. The suppressor grid of the pentode, however, is maintained at a mean potential slightly below that of the cathode but at the same H.F. potential as the screen grid. An increasing potential on the suppressor and screen grids results in a decreasing input current to the tuned circuit connected in series with the screen grid supply, so that the valve appears as a negative resistance across this circuit. The arrangement is outlined in Fig. **9**, the tuned circuit switching arrangements being omitted.

The frequency changer panel described is the original laboratory experimental model. Experience in the actual use of the equipment has enabled certain suggestions for improvement to be made, and these will be incorporated in a later design.

The Crystal Controlled Oscillator.

When making measurements of delay and differential delay on repeater lengths of coaxial cable by insertion phase shift measurements, it is essential to use an oscillator of accurately known and very constant frequency to feed the circuit under test.

The crystal controlled oscillator was designed primarily for such a purpose, and consists of a 50 kc/s rectangular quartz plate crystal oscillating in a temperature controlled chamber, together with means for producing, selecting and amplifying harmonics from the 2nd up to the 64th.

The crystal valve is a pentode used as a triode oscillator with an electron-coupled output circuit. This arrangement was adopted with a view to minimising the effect upon the crystal frequency of any changes in the output circuit. The crystal is of the gold sputtered type, and is mounted horizontally. The holder is of a special type designed to grip and locate the crystal so that it cannot shift, even if the apparatus is subjected to rough usage as may occur during transport. The oven is of very simple construction, consisting of a section of heavy gauge brass tube, and the temperature is thermostatically controlled at about 50° C.

The fundamental 50 kc/s component is removed by a 75 kc/s H.P. filter in the anode circuit of the crystal valve, and the 2nd, 4th, 6th or 8th harmonic is selected for further amplification by one of four band-pass filters. To improve this selection a second set of filters is incorporated in the second amplifier stage, and amplitude equalisation of the four frequencies is provided in the third stage. Harmonics of any one of these frequencies are produced in the fourth stage, any desired harmonic being finally selected by manually tuned band-pass circuits covering the range of 100 kc/s to 3·2 Mc/s in four ranges. Two further stages of harmonic amplification are provided, and the oscillator is capable of supplying at least 5 V (R.M.S.) into a load of 75 ohms at any frequency which is a multiple of 200, 300, or 400 kc/s up to 3·2 Mc/s. This also applies to frequencies which are odd multiples of 100 kc/s at frequencies up to about 2·0 Mc/s, these harmonics falling off somewhat above the latter frequency. At a frequency of 3·2 Mc/s, where the selectivity is worst, the discriminations to frequencies separated by 100, 200, 300, and 400 kc/s are respectively about 25, 49, 69, and 85 db.

The random change of frequency measured over a period of some hours was about 0·2 c/s, and a change of that order also occurred when the apparatus was subjected to a severe mechanical shock.

The oscillator panel is shown in Fig. **8**, to the left of the phasemeter panel.

The Network Termination Panel.

This panel is shown immediately below the crystal controlled oscillator in Fig. **8**, and serves as junction and distributing point between the oscillator, frequency changer panel and the network under test. Provision is also made for the insertion of inequality pads so that networks having impedances other than 75 ohms may be measured. This facility takes the form of copper screening boxes containing soldering tag connecting points where series or shunt resistance elements may be inserted. A 75 ohm attenuator consisting of three pads, 5, 10 and 20 db., is included in the input lead which is common to both the network under test and the " reference phase " side of the frequency changer panel.

Power Supplies.

The complete equipment is designed to work from 50 c/s A.C. mains, each rack being self contained. The power pack for the frequency changer panel supplies stabilised H.T. and G.B. voltages of 240 and 120 V respectively. The heaters of the valves are supplied from a separate 4 V transformer, stabilised on the " saturated core " principle.

Similar power equipment is provided for the crystal controlled oscillator.

Mains Distribution Panels.

In order that the apparatus should be readily transportable it was decided to use racks specially constructed of standard duralumin sections.

The mains distribution panels are fitted at the bottom of each rack. Connection to the 50 c/s supply is effected at the back to one panel by a 3-way shielded plug and socket, the two panels being interconnected by a short cable link and similar plugs and sockets to facilitate separation of the two racks for transport. Fuses are mounted on the front of the panels, as shown in Fig. **8**.

Operation.

The procedure in making measurements of insertion phase shift is both simple and straightforward. Certain precautions are, however, necessary if accuracy is to be attained, especially when operating at high frequencies and when the network to be measured introduces insertion loss. Under these conditions the following procedure is adopted. This can best be understood by reference to Figs. **2** and **9**.

The " network in " and " network out " sockets on the left-hand side of the network termination panel are first connected together by a short length of flexible coaxial lead, and the signal oscillator set to the required frequency. The attenuator on the frequency changer panel (" variable phase " circuit) is set to zero and the output from the network termination panel adjusted to about 1 mV, by the voltmeter on the oscillator and the attenuator on the network termination panel. The beating oscillator is then adjusted to obtain the necessary 750 c/s difference frequency as shown by the resonance indicator on the phasemeter panel. Having obtained resonance the output voltages, indicated by the two rectifier type voltmeters on the phasemeter panel, are adjusted to 110 V by varying the output from the signal oscillator. The two voltages are made equal either by the attenuator on the frequency changer panel or by the preset control of amplifier bias. The " zero phase shift " control is then adjusted so that the phasemeter reads zero. The beating oscillator is now changed in frequency by 1,500 c/s so that it heterodynes on the other side of the signal oscillator frequency, and resonance again obtained. The phasemeter reading should now be zero as before.

The network to be measured, assumed to be of 75 ohms impedance, is now connected to the " network in " and " network out " sockets. If there is appreciable loss in the network it is necessary again to equalise the output voltages by inserting attenuation in the attenuator on the frequency changer panel, and increasing the output of the signal oscillator. The attenuator is designed to have negligible phase shift at 750 c/s.

After checking for resonance, the phasemeter reading is taken, the beating oscillator frequency changed so as to heterodyne on the other side of the input frequency, and the phasemeter reading again noted. The phasemeter readings, converted to true phase angles by the calibration correction curve, would be found to be equal and of opposite sign if there were no other errors in the apparatus. By taking the mean of these angles as the magnitude of the required angle the random errors in the measurement, such as reading error and friction in the phasemeter, may be reduced. The sign of the required angle of insertion phase shift is that of the reading obtained when the beating oscillator frequency is higher than the input signal frequency.

It has been found that, at the upper end of the frequency range, if the zero adjustment is made with the beating oscillator frequency on one side of the input frequency this adjustment is changed by an angle up to about 4° when the beating oscillator frequency is changed to the other side of the input frequency. It is probable that this effect is due to coupling between the frequency changers and should be reduced with the improved form of construction proposed. A similar effect is also noticed when measuring phase angles other than zero, the two readings corresponding to the two beating oscillator frequencies not being exactly equal and opposite. It is therefore advisable to adjust the zero at about 100 kc/s and thereafter leave the setting fixed, merely noting the phasemeter readings for the two beating oscillator frequencies and the change in reading when the network is inserted. Some care is necessary in the recording of measurements as confusion is possible, especially when angles in the neighbourhood of 0°, 180° and 360° are being measured.

The insertion phase shift of the apparatus under test is equal to the corrected reading of the phasemeter $\pm 2n\pi$ radians, where n is a positive integer. The value of ' n ' may be found from a knowledge of the elements of the circuit under test, or on a long cable circuit it can be found by making a large number of measurements from a low frequency upwards, counting the revolutions of the phasemeter as the frequency is increased. A continuously variable oscillator is desirable for such a comprehensive test, but exact phase measurements can be made at the multiples of 100 kc/s given by the crystal controlled oscillator.

Conclusion.

The apparatus which has been described has already been put to considerable use for the measurement of insertion phase shift at radio frequencies. The rapidity with which measurements can be made, and the absence of any involved calculation in obtaining results, are features which have been generally approved.

An obvious simplification would result if the two oscillators used in the scheme—these two oscillators have to be variable, but at the same time maintained at a fixed frequency separation of 750 c/s—were arranged in such a manner that they could be operated by a single control to give the fixed frequency difference automatically. Other methods, such as the use of two H.F. oscillators of fixed frequency, but differing by 750 c/s, suitably combined with the output of a variable H.F. oscillator to give two outputs of variable H.F. separated by the required constant difference frequency, could also be used with advantage.

Acknowledgment.

The authors are indebted to Mr. G. H. Fogg of the Radio Branch, Engineer-in-Chief's Office, for valuable assistance in preparing this article for publication.

Appendix I. Theory of the Method of Measurement.

Let the two potentials between which it is desired to know the phase difference be :

$$V_1 \sin \omega t$$
$$\text{and } V_2 \sin (\omega t + \phi)$$

These are applied separately to the signalgrids (G4) of two octode frequency changer valves, Nos. 1 and 2.

Let the voltage applied to the oscillator grids (G1) of both octodes, from the common oscillator, be :

$$V_3 \sin \omega_1 t$$

Over the linear range of the frequency changer valves the law relating the anode current and the voltages on G1 and G4, assuming constant potentials on the remaining electrodes, can be expressed in the form :

$$i_{a1} = K_1 (V_{g1} + a)(V_{g4} + \beta) \text{ for octode No. 1.}$$
$$\text{and } i_{a2} = K_2 (V_{g1} + a)(V_{g4} + \beta) \text{ for octode No. 2.}$$

where V_{g1} = potential on G1

V_{g4} = potential on G4

and K_1, K_2, a and β are constants.

Assuming that the static (i.e. the bias) values of V_{g1} and V_{g4} are V'_{g1} and V'_{g4} on No. 1 octode, and V''_{g1} and V''_{g4} on No. 2 octode, it follows that :

$$i_{a1} = K_1(V_3 \sin \omega_1 t + V'_{g1} + a)(V_1 \sin \omega t + V'_{g4} + \beta)$$
$$i_{a2} = K_2(V_3 \sin \omega_1 t + V''_{g1} + a)(V_2 \sin(\omega t + \phi) + V''_{g4} + \beta)$$

The difference frequency, $(\omega - \omega_1)$, terms are by multiplication easily shown to be :

$$i_{a3} = \frac{K_1 V_1 V_3}{2} \cos \pm (\omega - \omega_1)t$$
$$i_{a4} = \frac{K_2 V_2 V_3}{2} \cos \pm \left\{(\omega - \omega_1)\, t + \phi\right\}$$

the + ve signs corresponding to $\omega_1 < \omega$

and − ve signs corresponding to $\omega_1 > \omega$

The phase angle of i_{a4} leads that of i_{a3} by ϕ if $\omega_1 < \omega$ and lags that of i_{a3} by ϕ if $\omega_1 > \omega$.

Appendix 2. Theory of the Phasemeter.

Referring to the simplified circuit of the phasemeter, Fig. 3, and the description of the instrument already given, suppose in the first place that steady currents are passed through coils A, A_1 and B. A radial flux will then be produced in the vanes of coil B and this will exert a force on the conductors of coils A and A_1. Relative movement between coils A and A_1 and the vane therefore tends to occur, and since the spindle alone is free to rotate it turns until the torque is zero, i.e. until the centre line of the vanes is parallel with the axis of A and A_1, the torque produced being dependent on the angle between this line and the axis of A and A_1. Similarly, if current is passed through A and A_1 and B_1, the vanes of B_1 will tend to take up a similar position relative to the axis of A and A_1, and the spindle will adopt a position differing from the first position by $\pi/2$ radians.

Suppose now that the terminals are connected in parallel to an alternating supply $V \sin \omega t$.

Then the current in A and A_1 will be

$$\frac{V}{R_1} \sin \omega t = I_1 \text{ (say)},$$

the current in B

$$\frac{V}{R} \sin \omega t = I_2 \text{ (say)},$$

and the current in B_1

$$\frac{V}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right) = I_3 \text{ (say)}.$$

Let the spindle be in such a position that the quadrants of coil B make an angle θ with the axis of A and A_1.

Then the torque due to B

$$= k\, I_1 I_2 \sin \theta$$
$$= k \frac{V^2}{RR_1} \sin^2 \omega t \sin \theta$$
$$= k \frac{V^2}{RR_1} \sin \theta \left[\frac{1 - \cos 2\omega t}{2}\right]$$

where k is a constant of the instrument.

The component of the torque varying at angular frequency 2ω produces angular vibration of the spindle at this frequency, but the angular momentum of the movement is normally large enough for this vibration to be negligible. The steady torque is then

$$\frac{kV^2}{RR_1} \frac{\sin \theta}{2}$$

The torque due to B_1 in the same direction as that due to B

$$= \frac{kV^2}{R\omega L} \sin \omega t \sin\left(\omega t - \frac{\pi}{2}\right) \sin\left(\theta - \frac{\pi}{2}\right)$$
$$= -\frac{kV^2}{R\omega L} \sin \omega t \cos \omega t \sin\left(\theta - \frac{\pi}{2}\right)$$
$$= -\frac{kV^2}{R\omega L} \frac{\sin 2\omega t}{2} \sin\left(\theta - \frac{\pi}{2}\right)$$

which has no steady component.

Hence the torque on the spindle is proportional to $V^2 \sin \theta$ and the spindle will take up a position such that $\sin \theta = 0$, i.e.: $\theta = 0$ or π.

Suppose now that the voltage applied to V_1V_2 leads that applied to M_1M_2 by an angle ϕ so that the new voltages are:

$V \sin \omega t$ at M_1M_2

and

$V \sin (\omega t + \phi)$ at V_1V_2

Then the torque due to B

$$= \frac{kV^2}{RR_1} \sin \omega t \sin (\omega t + \phi) \sin \theta$$
$$= \frac{kV^2}{RR_1} \left[\sin^2 \omega t \cos \phi + \cos \omega t \sin \omega t \sin \phi\right] \sin \theta,$$

the steady component being

$$\frac{1}{2} \frac{kV^2}{RR_1} \sin \theta \cos \phi.$$

The torque due to B_1 in the same direction as that due to B

$$= \frac{kV^2}{R_1\omega L} \sin \omega t \sin\left(\omega t - \frac{\pi}{2} + \phi\right) \sin\left(\theta - \frac{\pi}{2}\right)$$
$$= \frac{kV^2}{R_1\omega L} \sin\left(\theta - \frac{\pi}{2}\right) \left[\sin^2 \omega t \cos\left(\frac{\pi}{2} - \phi\right) - \sin \omega t \cos \omega t \sin\left(\frac{\pi}{2} - \phi\right)\right],$$

the steady component being

$$\frac{kV^2}{R_1\omega L} \sin\left(\theta - \frac{\pi}{2}\right) \frac{\cos\left(\frac{\pi}{2} - \phi\right)}{2}$$
$$= -\frac{1}{2} \frac{kV^2}{R_1\omega L} \cos \theta \sin \phi$$

Let $R = \omega L$.

Then the total torque

$$= \frac{1}{2} \frac{kV^2}{RR_1} \left[\sin \theta \cos \phi - \cos \theta \sin \phi\right]$$
$$= \frac{1}{2} \frac{kV^2}{RR_1} \sin (\theta - \phi).$$

Equating this to zero gives

$$\sin (\theta - \phi) = 0,$$
$$\text{or } \theta = \phi \pm n\pi.$$

A Mains Frequency Error Recorder

W. E. FINLASON, B.Eng.

U.D.C. 621.317.363

The apparatus described was developed to make long period observations of the fluctuations of the frequency of the A.C. supply mains. The type of record obtained is particularly suited to statistical analysis. Discrimination is provided between high and low frequency errors.

Introduction.

THE need for an accurate means of determining mains frequency error arose in connection with the desire to drive teleprinters and multi-frequency generators for V.F. systems by synchronous motors, and an investigation of the frequency variations of the 50 c/s A.C. supply mains became

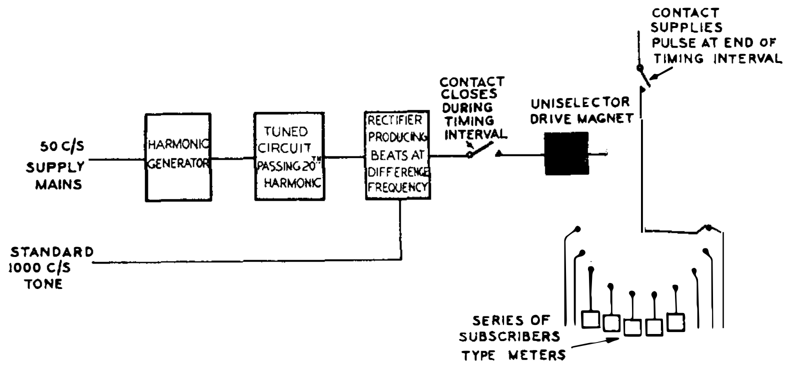


FIG. 1.—SCHEMATIC OF PRINCIPLE EMPLOYED.

essential. The present mains frequency error recorder differs essentially from an earlier model[1] in that differentiation is made between errors which are above, and errors which are below, normal mains frequency. The basic method of operating the recorder remains unchanged however.

Principle of Operation.

The principle of the recorder lies in the comparison of the twentieth harmonic of the A.C. mains frequency with a standard 1,000 c/s tone which has an accuracy of one part in ten million. The resulting beat frequency is a measure of the frequency error of the mains, and by totalling the number of beats in a given small interval of time a record of the average error during the time interval is obtained.

Reference to the schematic of Fig. 1 will enable the principle to be more clearly understood. The A.C. mains, after transformation down to a comparatively low voltage, are fed into a harmonic generator consisting of a full wave metal rectifier network. The pulsating rectified output from this network is passed through a selective circuit, which rejects all but the 1,000 c/s component, i.e., the twentieth harmonic of the mains frequency. This is now modulated with the standard 1,000 c/s tone, and, after rectification, the resulting low beat frequency which only in extreme instances would be as high as 10 impulses per second, is passed via a timing contact and an intermediate relay to the drive magnet of the beat counting uniselector. The latter steps forward at a rate proportional to the beat frequency, and at the termination of the timing period a pulse is caused to flow via the uniselector wiper to operate one of a series of subscriber's type meters which are wired to the uniselector bank, the various meters corresponding to the degrees of mains frequency error.

Discrimination between High and Low Frequency Errors.

To determine whether the error being recorded is an error above or below 50 c/s an extension of this method is required (see Fig. **2**). The standard tone is passed into a phase splitting network which produces two 1,000 c/s outputs which are 90 degrees out of phase with each other. These are each separately mixed with the twentieth harmonic of the A.C. supply mains, after which the two signals are fed separately into two valve rectifier (or detector) stages. The outputs of these stages are each at a very low, and of course variable, beat frequency, and will be found to have a phase angle with respect to each other of one-quarter of a cycle of the beat frequency, this point being explained more fully later.

The anode currents of the rectifier valves are passed through the anode relays F and S respectively, and therefore, if the effect of the relay contacts be ignored, one relay will operate 90 degrees earlier in the beat frequency cycle than the other. The effect of the F and S relay contacts is, however, as follows: if the mains frequency is low relay S is the first to

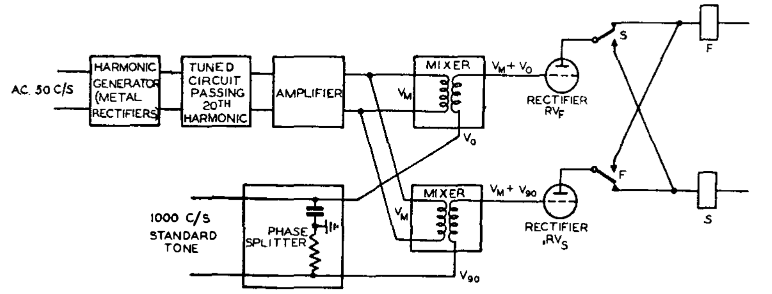


FIG. 2.—SCHEMATIC OF RECORDER WITH HIGH AND LOW FREQUENCY DISCRIMINATION.

operate, and in doing so it switches the anode current of the other rectifier valve to its own coil, thus preventing the other relay (F) from operating. Hence relay S alone will operate to the pulse of beat frequency. If, however, the mains frequency is high relay F is the first in the beat frequency cycle to

[1] The earlier model is described in a paper by Messrs. F. O. Morrell and G. R. Oman, which was read before the Institution of Electrical Engineers in March, 1940. (Published in November, 1940.) Much of the credit for the earlier development of this recorder is due to Mr. Oman, who unfortunately failed to recover from an operation which he underwent in 1938.

operate, and it will in a similar manner switch the anode current of the other valve to its own coil, preventing relay S from operating. Since either relay in operating disconnects the other only one relay is operated at each beat frequency pulse.

The effect of this switching system, therefore, is to cause relay F alone to pulse at the beat frequency when the mains frequency is higher than 50 c/s, whereas relay S alone will pulse when the mains are below 50 c/s. The method by which these pulses are appropriately recorded by a uniselector and a series of subscriber's meters will be discussed in detail at a later stage.

Vectorial Analysis of Conditions at the Mixing Stage.

The conditions prevailing at the mixing stage are best explained by the vector diagram (Fig. **3**). The

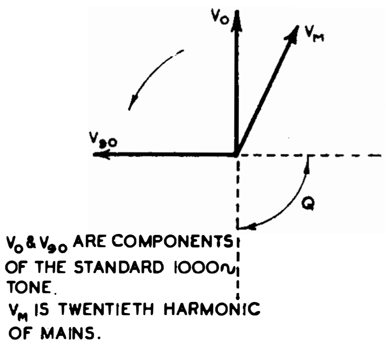


FIG. 3.—DIAGRAM OF THE VECTOR RELATIONSHIPS.

voltage vectors V_0 and V_{90} represent the two components of the standard 1,000 c/s tone, which are 90 degrees out of phase with each other, and voltage vector V_M represents the twentieth harmonic of the mains frequency. The vectors V_0 and V_{90} are rotating at 1,000 revs./sec. in the conventional anti-clockwise direction, and vector V_M is rotating in the same direction at a speed which may vary slightly above or below that of the vector system V_0 and V_{90}.

To appreciate the relative motion of the vectors consider the vectors V_0 and V_{90}, which are always 90 degrees apart, to be at rest. Then vector V_M will rotate slowly, i.e., at beat frequency, in a clockwise or anti-clockwise direction, according to whether the mains frequency is lower or higher than 50 c/s. If the latter frequency is exactly 50 c/s then there will, of course, be no relative movement of the vectors and V_M will appear stationary. The vector sum of V_M and V_0 will, after rectification, appear as the anode current of rectifier valve RV_F (Fig. **2**), and the vector sum of V_M and V_{90} will similarly appear as the anode current of rectifier valve RV_S.

If the mains frequency is high and vector V_M is rotating slowly in an anti-clockwise direction relative to V_0 and V_{90}, then it will be evident that the vector sum of V_M and V_0 reaches its maximum a quarter of a cycle of the beat frequency earlier than the vector sum of V_M and V_{90} reaches its maximum. Since these signal maxima coincide with the maxima of the anode currents in the rectifier valves the anode current in valve RV_F will rise earlier than the anode current in valve RV_S; in fact it will be earlier by one quarter cycle of the beat frequency.

Conversely if the mains frequency is low the vector V_M will be rotating slowly in a clockwise direction relative to V_0 and V_{90}, and in this instance the vector sum of V_M and V_{90} reaches its maximum a quarter of a cycle of the beat frequency before the vector sum of V_M and V_0 does likewise. Hence the anode current in the rectifier valve RV_S rises the earlier in the beat frequency cycle.

It must be realised that during the period in which the vector V_M passes through the sector of the diagram marked Q, the anode currents will both fall to a low value, and there will be a period during which both relays are simultaneously in the normal position. Hence according to the direction of rotation of the vector V_M as it leaves the sector Q of the diagram, so the appropriate valve anode current will rise the earlier and its corresponding relay will operate.

A more rigid mathematical analysis of the conditions at the mixing stage is included in the appendix.

Circuit Details.

The Pulse Generating Circuit.—The 1,000 c/s supply which is used as the frequency standard feeds more than one laboratory, and consequently its level is liable to fluctuate. It was also envisaged that this standard tone might have to be fed over long trunk lines, and it was, therefore, essential to include a constant volume amplifier (Fig. **4**) to ensure that equality of signal level was always maintained at the mixing stage. The constant volume amplifier consists of a high ratio step-up transformer feeding the grid of the amplifier valve via a high resistance. The voltage swing delivered by the transformer may be as much as 10 or 20 times the normal grid swing for the valve, the negative half cycles causing suppression of the anode current and the positive half cycles causing grid current to flow and dissipating the transformer output voltage as an RI drop in the grid resistance. The resulting anode current has a square

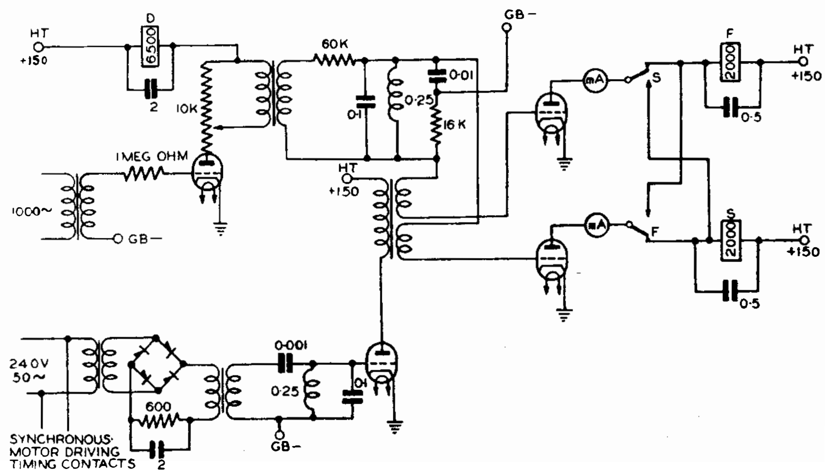


FIG. 4.—THE PULSE GENERATING CIRCUIT.

topped waveform of constant amplitude between values of 1,000 c/s input ranging from about 0·2 volts to 3 volts. The anode current of the valve is passed through a potentiometer and an interstage transformer, the potentiometer being adjusted initially to produce equal signal levels at the mixing stage. Subsequent variations in the input signal level will be taken care of by the constant volume amplifier, and this equality will not be disturbed.

It is undesirable to inject a square topped waveform into a phase-splitting circuit, and therefore the signal is passed through a "cleaning-up" circuit which restores it to its original sinusoidal waveform, this circuit consisting for simplicity of a series resistance feeding into a parallel tuned circuit. The resulting signal is passed to the phase splitting circuit which consists of a resistance and condenser in series, the centre point of the combination being stabilised at negative grid bias potential. Hence the outer points of the phase-splitting circuit bear voltages which are 90 degrees out of phase with each other, and these are each passed through separate secondary windings of a mixing transformer to the grids of the two final rectifiervalves. Theprimaryof this mixing transformer is supplied with the twentieth harmonic of the mains frequency in the following manner.

One of the secondary windings of the mains transformer supplies current at approximately 45 V to a bridge rectifier combination, consisting of four 12 element rectifiers, the direct current output of which is dissipated in a resistance. The superimposed alternating current output is transformed up and injected into a selective circuit which eliminates all but the 1,000 c/s component. The selective circuit consists of a small series condenser feeding into a parallel tuned circuit. The "Q" value of this circuit should be high since, in effect, a pulse is supplied to it once every 10 milliseconds, i.e., once for each time the rectified 100 c/s waveform touches the zero line and causes a discontinuity. In the intervals between these pulses the tuned circuit must remain oscillating on account of the energy received from the preceding pulse.

The self-oscillatory frequency of the circuit will not, however, be the twentieth harmonic of the mains, which, of course, varies slightly, but will in point of fact be purely a function of the L, C and R values of the circuit, which were adjusted initially to a self-oscillatory frequency of 1,000 c/s. At first this would appear to be an inherent defect, but in practice it is found that the slight phase-correction applied by the mains pulse every 10 milliseconds is sufficient to ensure that the average effective frequency passed by this circuit is the twentieth harmonic of the mains. This signal is amplified by a triode and passed through the primary of the mixing transformer referred to in a previous paragraph.

The operation of the mixing stages, rectifier valves and anode relays has already been discussed in considerable detail, and will not be alluded to again at this juncture.

The Recording Circuit.—Reference to Fig. 5 reveals the main details of the recording circuit. A discriminating relay SL is operated and locks if relay S pulses, whereas it releases and will remain normal if relay F should pulse. The condition of relay SL thus indicates whether the mains frequency is higher or lower than 50 c/s.

Measurement of the amount of the frequency error is effected by counting the number of pulses of the beat frequency in a given time period. A synchronous A.C. clock motor has an output shaft which revolves once in 15 seconds and a cam on this shaft is arranged to close a timing contact for 5 seconds every 15 seconds. A relief relay actuated by this timing contact causes impulses from either of the relays F or S to be fed to the uniselector drive magnet for the duration of the timing period, i.e., the uniselector will be stepped forward by as many beat frequency pulses as there are in 5 seconds.

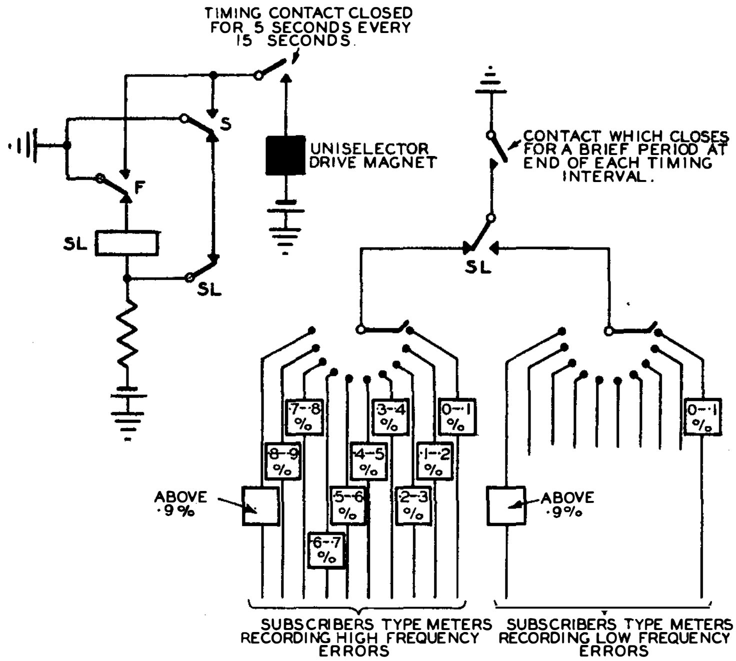


FIG. 5.—THE RECORDING CIRCUIT.

At the end of the recording period an impulse is fed via an SL discriminating contact and a uniselector wiper to one of the two 50-point banks where registration will be effected on the appropriate meter. The duration of the meter pulse and the subsequent homing of the uniselector are under the control of two slugged relays which are also actuated by the timing contact relief relay. There are two 50-point banks and ten meters are connected to each, an individual meter being wired to five successive contacts on the bank. The meters on one bank record the errors above 50 c/s, and those on the other bank record the errors below 50 c/s.

If, as an example, an instant at which the beat frequency is one pulse per second is examined, then the error is one cycle per 1,000 cycles, i.e., the mains error is 0·1 per cent. But in a 5-second period the uniselector will have moved forward 5 steps. Hence the first meter, which is wired to the first 5 contacts, records errors from zero to 0·1 per cent., the second meter errors from 0·1 per cent. to 0·2 per cent., and so on up to 1 per cent. error. If errors higher than 1 per cent. should occur they would be registered on the final meter which records any error greater than 0·9 per cent.

The meters are read at the commencement and at the termination of a testing period, or, on a long duration test, at a given hour each day. The total number of units recorded upon a given meter during the testing period represents the number of quarter minutes during which the corresponding degree of error was maintained.

Degree of Accuracy of the Recorder.

It will be evident from the foregoing that 0·1 per cent. change in frequency is the smallest change that is recorded upon the instrument, although changes of frequency of 0·02 per cent. of 50 c/s could be recorded if each uniselector step were wired to a separate meter.

The Resulting Records.

The type of record produced by this equipment is of particular value in statistical investigations where it is desired to estimate by the methods of probability the chance of the frequency error being greater than a given amount, or alternatively the percentage of time during which the error is less than a certain value. The " distribution " curves which are required for these calculations can be obtained directly from the meter readings which give the relative frequency of occurrence of the various degrees of error, since for each period of 15 seconds during which the error is of a particular value, one unit is recorded on the appropriate meter.

A typical " cumulative " distribution curve constructed from the results obtained on the recorder is shown in Fig. 6. The small crosses indicate the actual readings and the curve is the " normal error curve " which most nearly passes through these points. The correspondence between this curve and the actual points is for the most part very good.

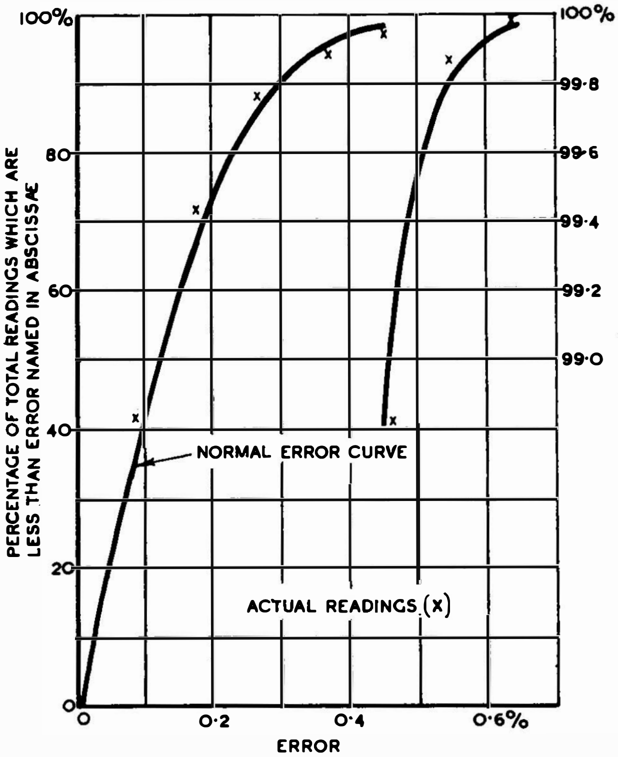


FIG. 6.—DISTRIBUTION CURVE OF ERRORS.

If a continuous chart record is required showing the actual frequency at any particular instant, a standard multi-pen recorder may be associated with the equipment. In this instrument twenty pens are arranged across the width of the chart in such a manner that twenty lines are drawn on the paper as it moves slowly forward under the control of a clockwork motor. Each pen has a small associated electro-magnet which is wired in parallel with its corresponding meter. The pulses which operate the meters also serve to move the pens sideways a short distance out of their normal lines. Hence a discreet mark is made every 15 seconds throughout the day and serves to show the actual error prevailing in the mains at that instant. A continuous chart is the type of record normally favoured by supply undertakings. An example of such a chart, showing the high frequency side only, is given in Fig. 7.

Alarms.

Two alarm relays are provided, the first relay D, Fig. 4, releasing if the 1,000 c/s supply fails. Contacts of this relay break the recording circuit and ensure that no fictitious readings are recorded on the meters. Failure of the 50 V supply would leave the valves

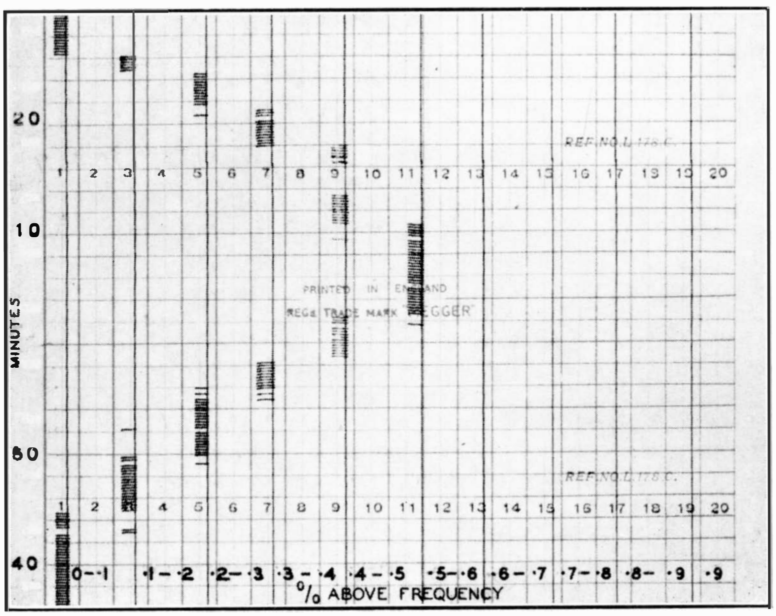


FIG. 7.—FREQUENCY ERROR CHART RECORD.

without any negative grid bias supply. This condition is guarded against by the second relay releasing and disconnecting the high tension supply to the valves.

Conclusion.

The general appearance of the laboratory model of the recorder may be seen from Fig. 8. A much more compact arrangement could readily be effected since in this laboratory model accessibility was the keynote of the arrangement.

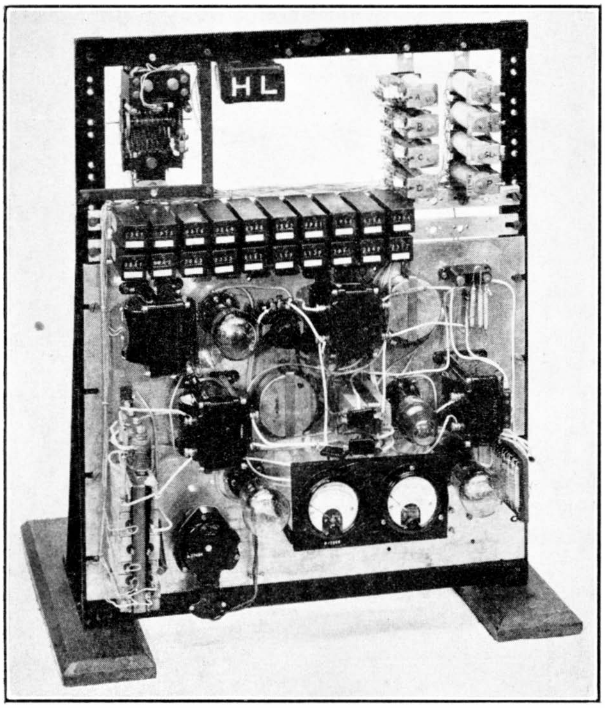


FIG. 8.—GENERAL APPEARANCE OF THE RECORDER.

It may be mentioned that as a result of the measurements made it was considered impossible to drive the multi-frequency generators by synchronous A.C. motors, although as far as frequency and consequently speed variations were concerned, the application of a synchronous motor drive to teleprinters was quite practicable.

APPENDIX.

Mathematical Theory.

In this recorder the problem of determining whether the frequency error is positive or negative resolves itself into the issue of discovering which of two frequencies is the higher. As has been previously stated, this is effected by splitting one frequency into two components at 90 degrees phase angle to each other and then beating each component separately against the second frequency.

If $E \sin \omega_1 t$ and $E \sin (\omega_1 t + \pi/2)$ are the two components of the first frequency, and $E \sin \omega_2 t$ is the second frequency, then after the appropriate additions the following waveforms are present in the two separate circuits :—

CIRCUIT 1.

$$e_1 = E \sin \omega_1 t + E \sin \omega_2 t$$

Let the difference frequency $\omega_1 - \omega_2$ be equal to ω

$$\therefore e_1 = E\left\{\sin (\omega_2 + \omega)t + \sin \omega_2 t\right\}$$

$$= E\left\{\sin \omega_2 t \cos \omega t + \cos \omega_2 t \sin \omega t + \sin \omega_2 t\right\}$$

$$= E\left\{(1 + \cos \omega t) \sin \omega_2 t + \sin \omega t \cos \omega_2 t\right\}$$

$$= E\left\{A \sin (\omega_2 t + \phi_1)\right\}$$

where $A^2 = (1 + \cos \omega t)^2 + \sin^2 \omega t$

and $\tan \phi_1 = \dfrac{\sin \omega t}{1 + \cos \omega t}$

$$\therefore A = \sqrt{(1+\cos \omega t)^2 + \sin^2 \omega t} = \sqrt{2 + 2\cos \omega t}$$

Hence A (and therefore e_1) reach maximum values at the beat or difference frequency when $\cos \omega t = 1$.

i.e., when $\omega t = 0, 2\pi, 4\pi \ldots.$

irrespective of whether ω is positive or negative.

The radical term appears to introduce an indeterminacy of sign. This indeterminacy, which is actually counteracted by a reciprocal indeterminacy in ϕ_1, may be ignored, however, since in a valve detector or rectifier stage it is the time interval between successive maxima, irrespective of their sign, which is the cycle time of the beat frequency.

CIRCUIT 2.

$$e_2 = E \sin \left(\omega_1 t + \frac{\pi}{2}\right) + E \sin \omega_2 t$$

$$= E\left\{\cos \omega_1 t + \sin \omega_2 t\right\}$$

Again let the difference frequency $\omega_1 - \omega_2$ be equal to ω

$$\therefore e_2 = E\left\{\cos (\omega_2 + \omega)t + \sin \omega_2 t\right\}$$

$$= E\left\{\cos \omega_2 t \cos \omega t - \sin \omega_2 t \sin \omega t + \sin \omega_2 t\right\}$$

$$= E\left\{(1 - \sin \omega t) \sin \omega_2 t + \cos \omega t \cos \omega_2 t\right\}$$

$$= E\left\{B \sin (\omega_2 t + \phi_2)\right\}$$

where $B^2 = (1 - \sin \omega t)^2 + \cos^2 \omega t$

and $\tan \phi_2 = \dfrac{\cos \omega t}{1 - \sin \omega t}$

$$\therefore B = \sqrt{(1 - \sin \omega t)^2 + \cos^2 \omega t} = \sqrt{2 - 2\sin \omega t}$$

Hence B and therefore e_2 reach maximum values at the beat or difference frequency when $\sin \omega t = -1$, i.e., when ωt is numerically equal to $3\pi/2$, $7\pi/2$, $11\pi/2$, etc., if ω is positive, and when ωt is numerically equal to $\pi/2$, $5\pi/2$, $9\pi/2$, etc., if ω is negative.

Hence when $\omega_1 > \omega_2$, i.e. when ω is positive, the beat frequency voltage in the second circuit leads that in the first circuit by $\pi/2$, whereas when $\omega_1 < \omega_2$ and ω is negative the beat frequency voltage in the second circuit lags behind that in the first circuit by $\pi/2$. This is the desired result.

A Narrow Band Filter Using Crystal Resonators

U.D.C. 621.395.662.3

H. STANESBY, A.M.I.E.E., and
E. R. BROAD, B.A.

The article analyses a band-pass filter which, when some of the elements are crystal resonators, can be used to select a very narrow frequency band. The limitations imposed by the use of resonators are determined and an example is given of the performance obtained in practice. The computed and measured insertion loss characteristics are in close agreement.

Introduction.

IN his introduction[1] to the study of quartz crystal filters Mason refers briefly to a lattice filter in which each arm consists of a resonator in parallel with a condenser. The filter has, it appears, a very narrow pass-band, with a loss characteristic which can be made to rise quickly just outside, and the absence of inductors with their accompanying dissipation suggests that the loss in the pass-band might be very low. As such a filter is likely to be useful it has been analysed and the results are the subject of this article.

A circuit diagram of the filter is given in Fig. **1** (i); and in (ii) of the same figure is shown the network

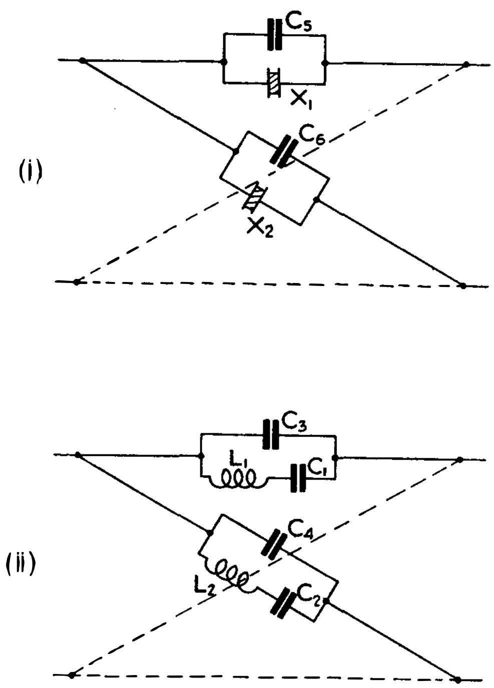


FIG. **1**.—NARROW-BAND CRYSTAL FILTER NETWORK

obtained when the resonators are replaced by their equivalent electrical circuits[1,2]. Most of the article will be devoted to studying the properties of the electrical network, and only towards the end will more than passing reference be made to the restrictions that the use of resonators imposes.

The series and lattice arms of the filter will each have reactance characteristics of the form shown in Fig. **2** (i). First let the critical frequencies f_A and f_B be different for the two arms, as shown in (ii) of the same figure, where the full curve refers to one arm and the dotted curve to the other. At very low and very

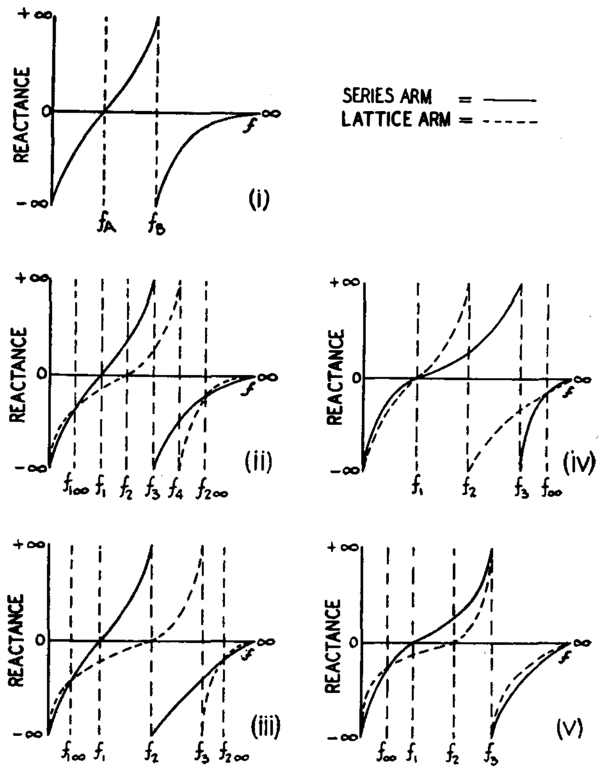


FIG. 2.—REACTANCE CHARACTERISTICS FOR NARROW-BAND CRYSTAL FILTER.

high frequencies the reactances of both arms will have the same sign and the filter will attenuate. Between these values there will be four frequencies at which the reactance of one arm changes sign relative to that of the other, hence there will be four frequencies at which the filter changes from attenuation to free transmission or vice versa, and two discrete pass-bands will exist. If a single critical frequency in one arm is made to coincide with one in the other arm a single pass-band will result. The three ways in which this may be done are shown in Fig. **2** (iii), (iv) and (v). When using resonators, the width of the pass-band for the arrangement of critical frequencies shown in (iii) can theoretically be given values up to about 0·8 per cent. of the mid-band frequency. For the other two arrangements the interval between one cut-off frequency and a frequency of peak attenuation on the opposite side of the second cut-off can reach only half this value. In practice these figures are reduced considerably by stray capacitances. Attention will therefore be confined to the arrangement of frequencies shown in Fig. **2** (iii), for which the limitations are less severe.

[1] *B.S.T.J.*, July 1934, pp. 405-452.
[2] *P.O.E.E.J.*, Vol. 31, pp. 254-264.

Analysis of Filter Section

Characteristic Impedance.

Let the elements of the series and lattice arms of the filter be denoted as shown in Fig. **1** (ii) and the critical frequencies numbered as in Fig. **2** (iii), where the full line and dotted curves apply to the series and lattice arms respectively. It is clear that f_1 and f_3 will be the two cut-off frequencies.

By applying Foster's Theorem it can be shown that the impedances Z_x and Z_y of the series and lattice arms, neglecting dissipation, are given respectively by :

$$Z_x = \frac{-j(\omega_1^2 - \omega^2)}{\omega C_3(\omega_2^2 - \omega^2)} \quad \ldots\ldots (1)$$

$$Z_y = \frac{-j(\omega_2^2 - \omega^2)}{\omega C_4(\omega_3^2 - \omega^2)} \quad \ldots\ldots (2)$$

$$(\omega_n = 2\pi f_n)$$

The characteristic impedance Z_k of the filter is given by :—

$$Z_k = \sqrt{Z_x Z_y}$$

$$= \frac{-j}{\omega\sqrt{C_3 C_4}} \cdot \sqrt{\frac{\omega_1^2 - \omega^2}{\omega_3^2 - \omega^2}} \quad \ldots\ldots (3)$$

The nominal characteristic impedance Z_o is the value of the characteristic impedance at the mid-band frequency $\omega_m/2\pi$, where $\omega_m^2 = \omega_1 \omega_3$, hence writing $\omega = \sqrt{\omega_1\omega_3}$ in equation (3) :

$$Z_o = \frac{-j}{\sqrt{\omega_1\omega_3 C_3 C_4}} \cdot \sqrt{\frac{\omega_1^2 - \omega_1\omega_3}{\omega_3^2 - \omega_1\omega_3}}$$

$$= \frac{-j}{\omega_3\sqrt{C_3C_4}} \cdot \sqrt{\frac{\omega_1^2\omega_3 - \omega_1\omega_3^2}{\omega_1\omega_3^2 - \omega_1^2\omega_3}}$$

$$= \frac{1}{\omega_3\sqrt{C_3C_4}} \quad \ldots\ldots (4)$$

Substituting Z_o in equation (3) :

$$Z_k = jZ_o \frac{\omega_3}{\omega} \sqrt{\frac{\omega_1^2 - \omega^2}{\omega_3^2 - \omega^2}} \quad \ldots\ldots (5)$$

By introducing ω_m, equal to $\sqrt{\omega_1\omega_3}$, and rearranging slightly, this expression may be changed into the following form which is more suitable for computation:

$$Z_k = Z_o \sqrt{\frac{\dfrac{\omega_3}{\omega_1} - \dfrac{\omega_m^2}{\omega^2}}{\dfrac{\omega_3}{\omega_1} - \dfrac{\omega^2}{\omega_m^2}}} \quad \ldots\ldots (6)$$

A curve showing the way in which Z_k varies with frequency for $\omega_3/\omega_1 = 1{\cdot}005$ is given in Fig. **3**. From this it will be seen that the characteristic impedance varies in the same direction over the whole of the pass-band ; there is therefore only one point at which the characteristic impedance can be made equal to the impedance of a constant resistance termination.

Propagation Constant.

The propagation constant P is given by :

$$P = 2\tanh^{-1}\sqrt{K} \quad \ldots\ldots (7)$$

where $K = \dfrac{Z_x}{Z_y}$

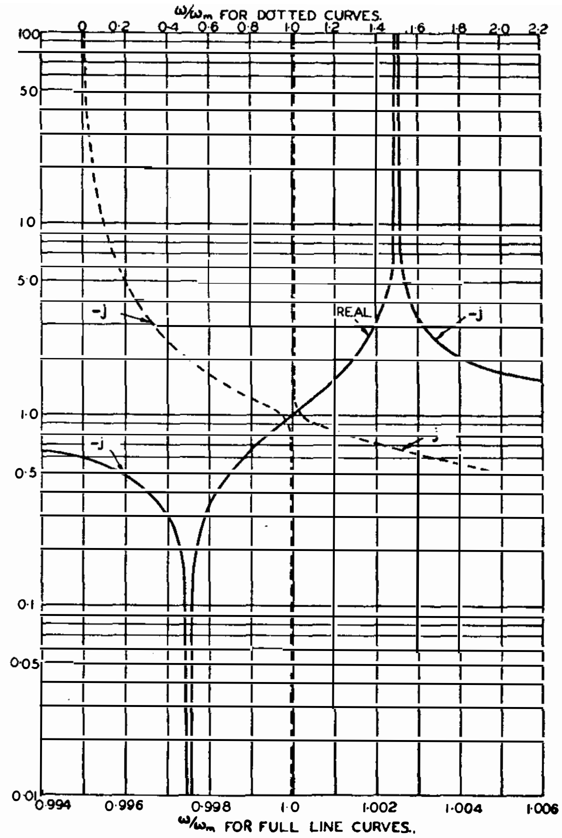


Fig. **3**.—Variation of Characteristic Impedance with Frequency.

Assuming as before that Z_x and Z_y are purely reactive then from equations (1) and (2) the value of K is given by :

$$K = \frac{C_4}{C_3} \cdot \frac{(\omega_1^2 - \omega^2)\ (\omega_3^2 - \omega^2)}{(\omega_2^2 - \omega^2)^2} \quad \ldots (8)$$

It will be seen that K is always real and is positive when $\omega < \omega_1$ and ω when $> \omega_3$ and negative when $\omega_1 < \omega < \omega_3$, i.e. when ω lies in the pass-band. Let the attenuation constant and phase constant be denoted by A and B respectively, then rewriting equation (7) :

$$P = A + jB = 2\tanh^{-1}\sqrt{K} \quad \ldots\ldots (9)$$

When K is positive its square root will be real and the solution of equation (9)[3] gives the following results :

$0 < K < 1$

$$\left.\begin{array}{l} A = 2\tanh^{-1}\sqrt{K} \\ B = \pm 2n\pi \end{array}\right\} \quad \ldots\ldots (10)$$

$K > 1$

$$\left.\begin{array}{l} A = 2\coth^{-1}\sqrt{K} \\ B = \pi \pm 2n\pi \end{array}\right\} \quad \ldots\ldots (11)$$

$K = 1$

$$\left.\begin{array}{l} A = \infty \\ \text{B is indeterminate} \end{array}\right\} \quad \ldots\ldots (12)$$

[3] *P.O.E.E.J.*, Vol. 31, p. 263.

This last condition corresponds to a discontinuity in the phase characteristic.

When K is negative its square root will be imaginary and the solution of equation (9) is given by:

$$0 > K \quad A = 0 \quad B = 2\tan^{-1}\sqrt{-K} \qquad \ldots\ldots\ldots\ldots(13)$$

Attenuation Constant.

Equations (8), (10), (11), (12) and (13) determine the attenuation constant. From (12) it is apparent that when K is + 1 the attenuation constant becomes infinite. The frequencies $f_{n\infty}$ at which this occurs are given by:

$$\frac{C_4}{C_3} \cdot \frac{(\omega_1^2 - \omega_\infty^2)(\omega_3^2 - \omega_\infty^2)}{(\omega_2^2 - \omega_\infty^2)^2} = 1 \ldots(14)$$

$$\text{Let } \frac{C_4}{C_3} = k^2 \ldots\ldots\ldots\ldots(15)$$

Equation (14) may then be rewritten in the form:

$$a\omega_\infty^4 + b\omega_\infty^2 + c = 0 \ldots\ldots(16)$$

where

$$a = 1 - k^2$$
$$b = -[2\omega_2^2 - k^2(\omega_1^2 + \omega_3^2)]$$
$$c = \omega_2^4 - k^2\omega_1^2\omega_3^2$$

Equation (16) has the form of a quadratic in ω_∞^2; its roots will therefore be of the form: $\alpha, -\alpha, \beta, -\beta$. When α and β are both real there will be two positive roots and two frequencies at which the attenuation constant becomes infinite. Both α and β become complex or imaginary together; when this happens there is no real frequency at which the attenuation constant becomes infinite.

An explicit solution of equation (16) is not necessary. When a filter is designed, the cut-off frequencies and frequencies of peak attenuation are usually fixed by the performance requirements and are used in determining the values of the filter elements. Expressions will therefore be found for the critical frequency f_2 and the ratio k^2 the capacitances C_4 and C_3, in terms of the cut-off frequencies f_1, f_3 and the frequencies $f_{1\infty}$, $f_{2\infty}$ at which the attenuation constant becomes infinite.

Equation (14) may be written in the form:

$$k^2(\omega_3^2 - \omega_\infty^2)^2 = \frac{\omega_3^2 - \omega_\infty^2}{\omega_1^2 - \omega_\infty^2} \cdot (\omega_2^2 - \omega_\infty^2)^2 \;\ldots(17)$$

and if it be assumed that:

$$\frac{\omega_3^2 - \omega_\infty^2}{\omega_1^2 - \omega_\infty^2} = y^2 \ldots\ldots\ldots\ldots(18)$$

both sides of (17) have the form of a perfect square. Thus y is a function of quantities which will be fixed arbitrarily and equation (17) may be used to express ω_2 and k in terms of these quantities. As $\omega_1 < \omega_\infty < \omega_3$ is a forbidden region for ω_∞, y^2 will always be positive and y will always be real.

From equation (18):

$$\omega_\infty^2 = \frac{y^2\omega_1^2 - \omega_3^2}{y^2 - 1} \ldots\ldots\ldots\ldots(19)$$

Substituting for ω_∞^2 in equation (17)

$$k^2\left(\omega_3^2 - \frac{y^2\omega_1^2 - \omega_3^2}{y^2-1}\right)^2 = y^2\left(\omega_2^2 - \frac{y^2\omega_1^2 - \omega_3^2}{y^2-1}\right)^2 \ldots(20)$$

whence, taking the square root of both sides and expanding:

$$y^2(\omega_2^2 - \omega_1^2) - yk(\omega_3^2 - \omega_1^2) + (\omega_3^2 - \omega_2^2) = 0 \ldots(21)$$

Since $\omega_1 < \omega_2 < \omega_3$, and k can be taken as positive, this equation has two positive roots which will be denoted by d_1 and d_2.

Proceeding, these roots, it will be remembered, need not be evaluated explicitly, but two parameters D and E will be introduced, equal respectively to the sum and product of the roots; hence from equation (21):

$$D = d_1 + d_2 = k \cdot \frac{\omega_3^2 - \omega_1^2}{\omega_2^2 - \omega_1^2} \ldots\ldots(22)$$

$$E = d_1 d_2 = \frac{\omega_3^2 - \omega_2^2}{\omega_2^2 - \omega_1^2} \ldots\ldots(23)$$

and from (18)

$$d_n = \sqrt{\frac{\omega_3^2 - \omega_{n\infty}^2}{\omega_1^2 - \omega_{n\infty}^2}} \ldots\ldots\ldots\ldots(24)$$

$$n = 1, 2.$$

using equations (22) and (23) it can be shown that

$$\omega_2^2 = \frac{E\omega_1^2 + \omega_3^2}{E + 1} \ldots\ldots\ldots\ldots(25)$$

$$k = \frac{D}{E + 1} \ldots\ldots\ldots\ldots(26)$$

Thus ω_2^2 and k have been expressed as functions of the frequencies of infinite attenuation and the cut-off frequencies.

Parameters D and E.—When electrical elements are used, as distinct from resonators, the only restrictions imposed on equations (22) and (23) are that k is positive and $\omega_1 < \omega_2 < \omega_3$, hence D and E may be given any real, positive values. The frequencies at which the attenuation constant is to be infinite may be located anywhere outside the pass band, one on either side or both on the same side, or if desired one or both of them can be made to disappear by giving them imaginary values.

It is important to consider the significance of the parameters D and E. Equation (23) shows that E is numerically equal to the ratio of the intervals $\omega_3^2 - \omega_2^2$ and $\omega_2^2 - \omega_1^2$, and from equation (26) it can be seen that D controls the ratio k^2 of the capacitances C_4 and C_3. It is obvious from the original definition of the parameters that they will also control the frequencies of infinite attenuation:

When E = 1, from equations (23) and (24):

$$\frac{\omega_3^2 - \omega_{1\infty}^2}{\omega_1^2 - \omega_{1\infty}^2} = \frac{\omega_1^2 - \omega_{2\infty}^2}{\omega_3^2 - \omega_{2\infty}^2}$$

Subtracting unity from each side:

$$\frac{\omega_3^2 - \omega_1^2}{\omega_1^2 - \omega_{1\infty}^2} = \frac{\omega_1^2 - \omega_3^2}{\omega_3^2 - \omega_{2\infty}^2}$$

whence:

$$\omega_1^2 - \omega_{1\infty}^2 = \omega_{2\infty}^2 - \omega_3^2$$

But when E is unity:

$$\omega_2^2 - \omega_1^2 = \omega_3^2 - \omega_2^2$$

These last two expressions reveal that ω_2^2 is now the common arithmetic mean of ω_1^2 and ω_3^2 and of $\omega_{1\infty}^2$ and $\omega_{2\infty}^2$. In other words when E = 1 :

$$\left.\begin{aligned} 2\omega_2^2 &= \omega_1^2 + \omega_3^2 \\ &= \omega_{1\infty}^2 + \omega_{2\infty}^2 \end{aligned}\right\} \quad \ldots\ldots (27)$$

It will be seen later than when E is unity the attenuation characteristic plotted against the square of the frequency is symmetrical about f_2^2 [4].

It is easy to show by referring again to equations (23) and (24) that as E is made greater or less than unity $\omega_{2\infty}^2 - \omega_3^2$ becomes greater or less than $\omega_1^2 - \omega_{1\infty}^2$. The parameter E therefore controls the degree of asymmetry of the attenuation characteristic. As a symmetrical attenuation characteristic is often desirable, the condition where E = 1 will be given special attention later. Moreover, one parameter is then virtually eliminated and the design formulae simplified.

The relationship between D and the positions of the frequencies of infinite attenuation is less instructive. One condition is of interest however :

when D = E + 1, i.e. when k = 1 :

$$d_1 + d_2 = d_1 d_2 + 1$$

factorising,

$$(d_1 - 1)\ (d_2 - 1) = 0$$

whence, $d_1 = 1$ or $d_2 = 1$

In the light of equation (24) this indicates that one of the frequencies of infinite attenuation is infinite.

Computation of Attenuation Constant.—Having introduced convenient design parameters the computation of the attenuation constant will now be considered.

The attenuation constant A in nepers is given by :

$$A = 2 \tanh^{-1} \sqrt{K} \quad (O < K < 1)$$
$$A = 2 \coth^{-1} \sqrt{K} \quad (K > 1)$$

Substituting in equation (8) using (15), (25) and (26), K may be expressed as a function of D, E, ω_1, ω_3 and ω :

$$K = \frac{D^2(\omega_1^2 - \omega^2)\ (\omega_3^2 - \omega^2)}{[E(\omega_1^2 - \omega^2) + (\omega_3^2 - \omega^2)]^2} \quad \ldots\ldots (28)$$

Let :

$$p^2 = \frac{\omega_3^2 - \omega^2}{\omega_1^2 - \omega^2} \quad \ldots\ldots (29)$$

then equation (28) may be written in the form :

$$K = \left(\frac{Dp}{E + p^2}\right)^2 \quad \ldots\ldots (30)$$

whence :

$$\left.\begin{aligned} A &= 2 \tanh^{-1} \frac{Dp}{E + p^2}, \quad 0 < \frac{Dp}{E + p^2} < 1 \\ A &= 2 \coth^{-1} \frac{Dp}{E + p^2}, \quad \frac{Dp}{E + p^2} > 1 \end{aligned}\right\} \quad \ldots (31)$$

[4]It is interesting to note that if the frequencies of infinite attenuation are arranged so that $\omega_{1\infty}\ \omega_{2\infty} = \omega_1\ \omega_3$ the resulting attenuation characteristic is symmetrical on a logarithmic frequency scale.

When E = 1, K involves the parameter D only and :

$$K = \left(\frac{Dp}{1 + p^2}\right)^2 \quad \ldots\ldots (32)$$

$$\left.\begin{aligned} A &= 2 \tanh^{-1} \frac{Dp}{1 + p^2}, \quad 0 < \frac{Dp}{1 + p^2} < 1 \\ A &= 2 \coth^{-1} \frac{Dp}{1 + p^2}, \quad \frac{Dp}{1 + p^2} > 1 \end{aligned}\right\} \quad \ldots (33)$$

It is easy to show that for this condition the attenuation constant plotted against ω^2 is symmetrical about ω_2^2. Let ω assume in turn any two values ω_a and ω_b such that ω_a^2 and ω_b^2 are symmetrical with respect to ω_2^2, then :

$$\omega_b^2 - \omega_2^2 = \omega_2^2 - \omega_a^2$$

Using equation (27) this may be rewritten :

$$\omega_b^2 = \omega_1^2 + \omega_3^2 - \omega_a^2 \quad \ldots\ldots (34)$$

If p_a and p_b are the values of p corresponding to $\omega = \omega_a$ and $\omega = \omega_b$ respectively, then from equations (29) and (34) :

$$p_a = \frac{1}{p_b}$$

But the value of A given by (33) remains unchanged if p is replaced by its reciprocal, hence the attenuation constant has the same value for $\omega = \omega_a$ as it does for $\omega = \omega_b$.

Expressions (31) and (33) are specially adapted to computation. The use of the variable p instead of ω renders the expressions independent of the location and width of the pass-band and allows curves to be constructed which are of general application.

The symmetry of the attenuation characteristic obtained when E is unity is of special importance. Curves have therefore been computed for this condition which show the relationship between A and p with D as parameter. These are reproduced in Fig. **4.**

Phase Constant.

It is sometimes desirable to know the way in which the phase constant B varies in the pass-band. This will therefore be considered briefly.

From equation (13) the value of B in the pass-band is given by :

$$B = 2 \tan^{-1} \sqrt{-K}$$

Substituting in the expression for K given in (30) using the relationship :

$$q^2 = -p^2 = \frac{\omega_3^2 - \omega^2}{\omega^2 - \omega_1^2} \quad \ldots\ldots (35)$$

$\sqrt{-K}$ may be written as

$$\sqrt{-K} = \frac{Dq}{E - q^2} \quad \ldots\ldots (36)$$

In the pass-band q^2 is positive and q is therefore real. The phase constant is then given by :

$$B = 2 \tan^{-1} \frac{Dq}{E - q^2} \quad \ldots\ldots (37)$$

This is a convenient expression for calculation.

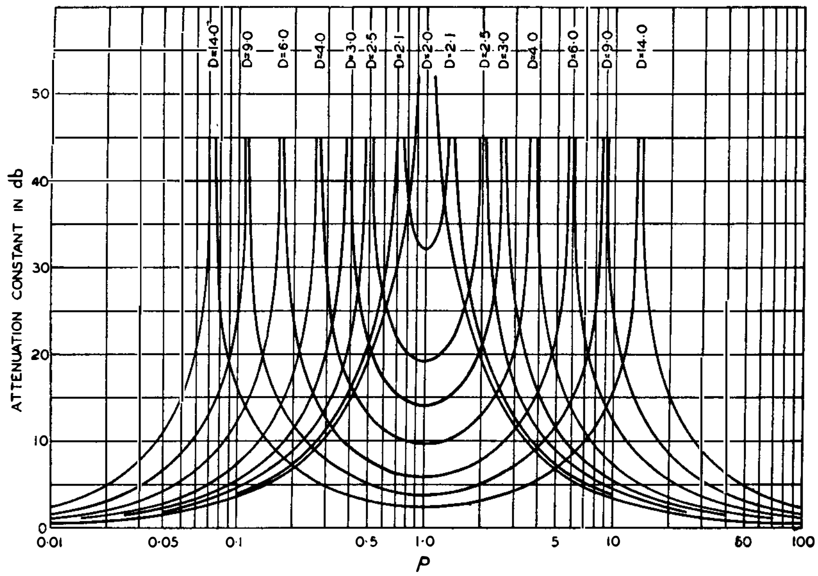


FIG. **4**.—CURVES FOR COMPUTATION OF ATTENUATION CONSTANT.

It will be seen that B depends upon the parameters D and E. The latter may therefore be used for adjusting either the attenuation constant or the phase constant characteristic.

When E = 1 :

$$B = 2 \tan^{-1} \frac{Dq}{1 - q^2} \qquad \text{(38)}$$

Curves showing the relationship between B and q, with D as parameter are given for this condition in Fig. **5**.

It will be seen from Fig. **1** (ii) that the series and lattice arms of the filter have the same configuration, and that each may be regarded as the limiting condition of two resonant circuits in parallel where one resonance frequency has receded to infinity. By applying Foster's Theorem, paying due regard to the numbering of the critical frequencies given in Fig. **2** (iii), it can be shown that :

$$L_1 = \frac{1}{C_3 (\omega_2^2 - \omega_1^2)} \qquad \text{(39)}$$

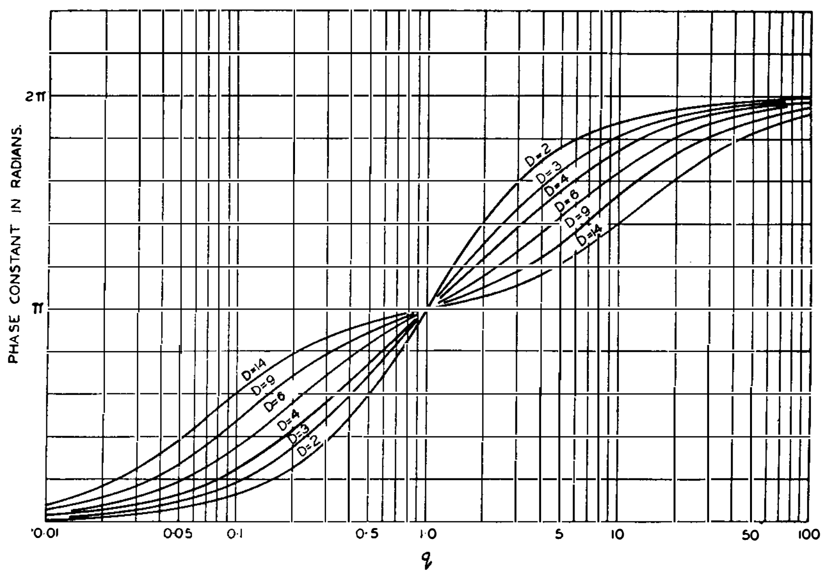


FIG. **5**.—CURVES FOR COMPUTATION OF PHASE CONSTANT.

Values of Electrical Elements.

Having studied the properties of the filter network in some detail and introduced convenient parameters it remains to derive expressions for the individual filter elements before specific networks can be designed.

$$C_1 = \frac{C_3 (\omega_2^2 - \omega_1^2)}{\omega_1^2} \qquad \text{(40)}$$

$$L_2 = \frac{1}{C_4 (\omega_3^2 - \omega_2^2)} \qquad \text{(41)}$$

$$C_2 = \frac{C_4 (\omega_3^2 - \omega_2^2)}{\omega_2^2} \qquad (42)$$

From equation (4):

$$\sqrt{C_3 C_4} = \frac{1}{\omega_3 Z_o} \qquad (43)$$

and a further relationship between C_3 and C_4 can be obtained from (15) and (26), namely:

$$\sqrt{\frac{C_4}{C_3}} = k = \frac{D}{E+1} \qquad (44)$$

Using equations (43) and (44) the values of C_3 and C_4 may be found:

$$C_3 = \frac{1}{\omega_3 Z_o} \cdot \frac{E+1}{D} \qquad (45)$$

$$C_4 = \frac{1}{\omega_3 Z_o} \cdot \frac{D}{E+1} \qquad (46)$$

From equation (25) the expressions involving ω_2^2 in (39) to (42) may be written in terms of ω_1^2, ω_3^2, D and E:

$$\omega_2^2 - \omega_1^2 = \frac{\omega_3^2 - \omega_1^2}{E+1} \qquad (47)$$

$$\omega_3^2 - \omega_2^2 = \frac{E(\omega_3^2 - \omega_1^2)}{E+1} \qquad (48)$$

Finally, substituting in equations (39) to (42) using (25) and (45) to (48) the values of the elements L_1, C_1, L_2 and C_2 are obtained:

$$L_1 = \omega_3 Z_o \cdot \frac{1}{\omega_3^2 - \omega_1^2} \cdot D \qquad (49)$$

$$L_2 = \omega_3 Z_o \cdot \frac{1}{\omega_3^2 - \omega_1^2} \cdot \frac{(E+1)^2}{D} \qquad (50)$$

$$C_1 = \frac{1}{\omega_3 Z_o} \cdot (\omega_3^2 - \omega_1^2) \cdot \frac{1}{D\omega_1^2} \qquad (51)$$

$$C_2 = \frac{1}{\omega_3 Z_o} \cdot (\omega_3^2 - \omega_1^2) \cdot \frac{DE}{(E+1)(E\omega_1^2 + \omega_3^2)} \qquad (52)$$

When $E = 1$ the expressions for the elements reduce to:

$$L_1 = \omega_3 Z_o \cdot \frac{1}{\omega_3^2 - \omega_1^2} \cdot D \qquad (53)$$

$$L_2 = \omega_3 Z_o \cdot \frac{1}{\omega_3^2 - \omega_1^2} \cdot \frac{4}{D} \qquad (54)$$

$$C_1 = \frac{1}{\omega_3 Z_o} \cdot (\omega_3^2 - \omega_1^2) \cdot \frac{1}{D\omega_1^2} \qquad (55)$$

$$C_2 = \frac{1}{\omega_3 Z_o} \cdot (\omega_3^2 - \omega_1^2) \cdot \frac{D}{2(\omega_1^2 + \omega_3^2)} \qquad (56)$$

$$C_3 = \frac{1}{\omega_3 Z_o} \cdot \frac{2}{D} \qquad (57)$$

$$C_4 = \frac{1}{\omega_3 Z_o} \cdot \frac{D}{2} \qquad (58)$$

Limitations Imposed by Resonators.

It is not proposed to study the properties of quartz crystal resonators in detail; this has already been done by Mason[5]. The restrictions in design imposed by the use of these resonators will, however, be considered briefly.

Referring to Fig. **1** (i) and (ii) it will be seen that the capacitances C_3 and C_4 in the series and lattice arms each consist of capacitance due to the resonator itself augmented by the external capacitances C_5 or C_6. When the external capacitances are zero the ratios C_3/C_1 and C_4/C_2 will be determined by the resonators alone, and their minimum values will therefore[5] be in the neighbourhood of 125.

Let the sum of these ratios equal S, then from equations (45), (46), (51) and (52):

$$S = \frac{C_3}{C_1} + \frac{C_4}{C_2} = \frac{(E+1)\,\omega_1^2}{\omega_3^2 - \omega_1^2} + \frac{E\omega_1^2 + \omega_3^2}{E(\omega_3^2 - \omega_1^2)} \qquad (59)$$

$$= \frac{\omega_1^2}{\omega_3^2 - \omega_1^2} \cdot \frac{E^2 + 2E + 1}{E} + \frac{1}{E} \qquad (60)$$

As a convenient measure of the fractional band-width let:

$$F = \frac{\omega_3^2 - \omega_1^2}{\omega_1^2} \qquad (61)$$

then from equation (60)

$$F = \frac{(E+1)^2}{SE - 1} \qquad (62)$$

It is desirable to find the value of E which makes F a maximum for a given value of S, then the band-width limitation imposed by S itself may be determined. By differentiating the right-hand side of equation (62) with respect to E and equating to zero, F may be shown to have its maximum value when:

$$\left.\begin{aligned} E &= 1 + \frac{2}{S} \\ &\doteqdot 1 \quad (S >> 1) \end{aligned}\right\} \qquad (63)$$

Substituting for E in (62) the corresponding value of F is given by:

$$\left.\begin{aligned} F &= 4\left(\frac{1}{S} + \frac{1}{S^2}\right) \\ &\doteqdot \frac{4}{S} \quad (S >> 1) \end{aligned}\right\} \qquad (64)$$

It is apparent from equation (64) that F must be a small fraction hence from equations (61) and (64)

$$F \doteqdot 2 \cdot \frac{\omega_3 - \omega_1}{\omega_1} \doteqdot \frac{4}{S}$$

When S has its minimum value of approximately 250 and E is unity the band-width expressed as a percentage of the lower cut-off frequency will have its greatest possible value of 0·8 per cent.

It will be seen that the maximum band-width is obtained for a given value of S when E is substantially unity, i.e. when the attenuation constant plotted against the square of the frequency is symmetrical. The parameter D does not enter into equation (62), and does not, therefore, affect the band-width if S and E are fixed.

In practice it is usually impossible to approach the maximum band-width of 0·8 per cent. owing to the presence of stray capacitance. It may be shown that if the effective capacitances across the input and output terminals of the filter each equal C_T, and if,

[5] *B.S.T.J.*, July 1934, pp. 406-412, 429 et seq.

in addition, there is a direct capacitance of C_8 in parallel with a resonator, the total equivalent capacitance effectively across the resonator is $C_8 + C_T$. Moreover, the higher the frequency at which a filter is designed to operate the lower will be the capacitance due to the resonators themselves owing to their smaller dimensions. Stray capacitance on high-frequency filters must, therefore, be reduced to a minimum if extremely narrow pass-bands are to be avoided.

The use of resonators also restricts the characteristic impedance. Referring back to equation (4) it will be seen that the nominal characteristic impedance varies inversely as $\sqrt{C_3 C_4}$. But C_3 and C_4 cannot be increased by adding capacitance to that of the resonators without reducing the band-width. Low values of characteristic impedance can, therefore only be realised for very narrow pass-bands or by using extremely thin resonators. In practice the nominal characteristic impedance usually lies between 5,000 and 100,000 ohms.

Performance of Typical Filter.

A considerable number of filters of the type considered has been made by the Post Office. Figs.

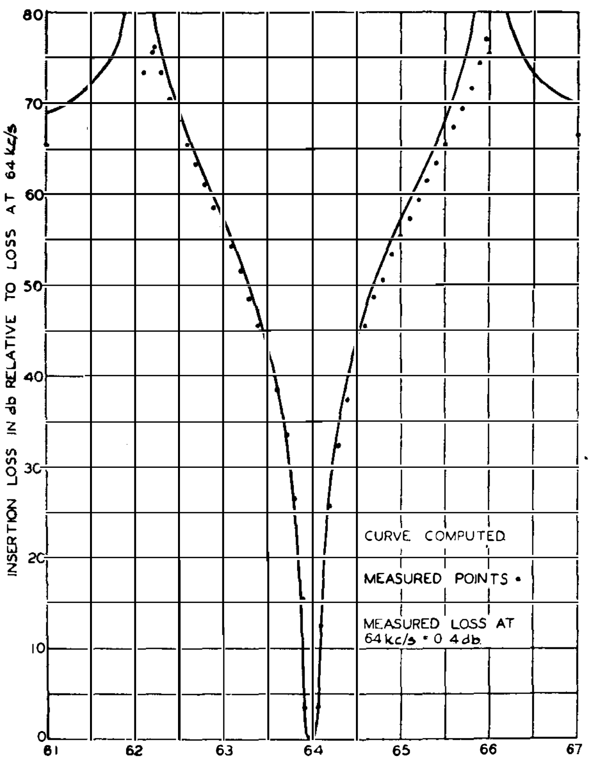


FIG. 6.—INSERTION LOSS CHARACTERISTIC.

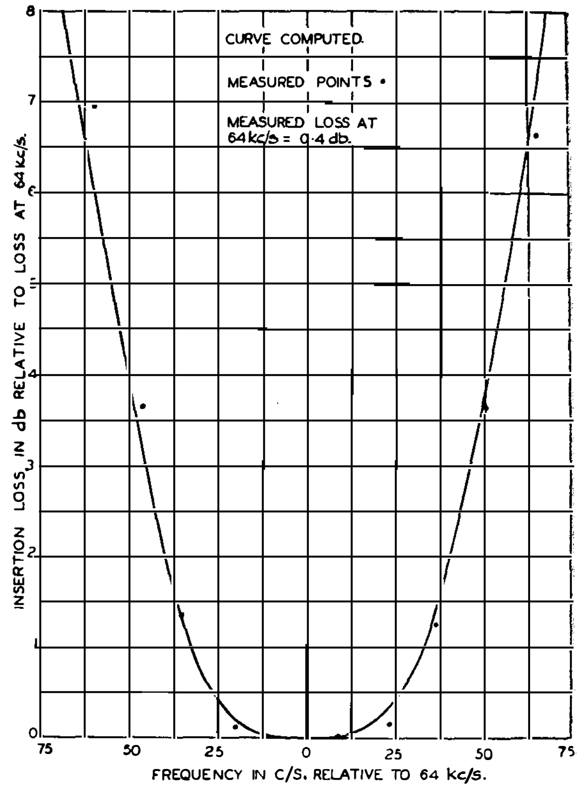


FIG. 7.—INSERTION LOSS CHARACTERISTIC IN PASS-BAND.

6 and 7 show the performance of one filter designed for the following parameter values :

$$f_1 = 63{\cdot}936 \text{ kc/s.} \qquad f_3 = 64{\cdot}064 \text{ kc/s.}$$
$$f_{1\infty} = 62{\cdot}136 \text{ kc/s.} \qquad f_{2\infty} = 65{\cdot}920 \text{ kc/s.}$$
$$Z_o = 20{,}000 \text{ ohms.}$$

The close agreement between the computed and measured values for attenuations below 60 db. is a satisfactory check of the analysis. For infinite attenuation the reactances of the series and lattice arms must be equal, and, in this particular filter, a departure from equality of 0·2 per cent. is sufficient to make the at enuation drop from infinity to 60 db. It is therefore understandable that the measured and computed attenuations differ somewhat, for values of the order of 60 db. or higher. In fact the smallness of the departure, and the low loss in the pass-band show how very closely a quartz crystal filter can be made to approach the ideal performance.

Acknowledgments.

The authors have pleasure in acknowledging their indebtedness to Mr. R. L. Corke who was associated with them in this work, and to Mr. H. J. S. Mason who obtained the data given in Figs. 6 and 7.

A Group Inverter for 12-Circuit Carrier Systems

U.D.C. 621.395.443.2

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An experimental inverter is described which enables 12-circuit systems, using lower-sideband transmission, to be connected to new 12-circuit systems, using upper-sideband transmission, without having to reduce the transmissions on both circuits to their audio-frequency components. The actual apparatus installed on the 12-circuit carrier trunk system may differ from the experimental model in some practical details.

Introduction.

EXISTING 12-circuit carrier systems (Nos. 5 and 6) installed in this country transmit a frequency band of 12 to 60 kc/s., with inverted sidebands, these being the lower sidebands of carriers the frequencies of which are multiples of 4 kc/s, from 16 to 60 kc/s.[1] In 1938 the C.C.I.F. recommended the use of erect sidebands for all international 12-circuit carrier systems, these being the upper sidebands of carriers the frequencies of which are multiples of 4 kc/s.[2] The British Post Office has extended this decision to cover all new equipment installed in this country (i.e., Carrier System No. 7).

The 12-circuit carrier trunk system of this country has been designed to allow switching of 12-circuit cable-pairs at certain centres via high frequency repeater distribution frames. At these frames, cable pairs, each carrying 12 channels, are connected through without the carrier transmissions being converted to their audio-frequency components, and some means had to be found to enable this to be accomplished when both old and new systems were to be interconnected. By means of a group inverter, as described in this article, a 12-circuit group can be inverted about its mid-band frequency (i.e., 36 kc/s), thus converting a 12-circuit group with lower sidebands of carrier frequencies of 16, 20 . . . 56, 60 kc/s to a 12-circuit group with upper sidebands of carrier frequencies of 56, 52 . . . 16, 12 kc/s. (Fig. 1.)

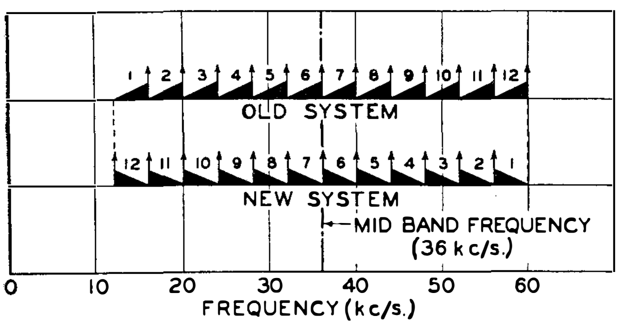

FIG. 1.—FREQUENCY ALLOCATION OF OLD AND NEW 12-CIRCUIT SYSTEMS.

Channel 1 of the old system then occupies the band corresponding to channel 12 of the new system, and channel 2 to that of channel 11, etc.

The Inversion of a Band of Frequencies.

A frequency band occupying the range a to b can be inverted by modulating it with a carrier of frequency (a + b). Among the resulting modulation products will be a band extending from [(a + b) — a] to [(a + b) — b], i.e., from b to a. Although this method is theoretically possible, it is not at present practicable for the inversion of multi-channel systems, since there will be a direct leak of the band a to b through the modulator, and this leak will obviously fall in the frequency range occupied by the required output of b to a, and will give rise to inter-channel crosstalk. The leak cannot be filtered out and can only be kept low by using a modulator which is highly balanced. In practice it is not possible to maintain a sufficiently high degree of balance.

A double modulation process can be used to overcome this difficulty. The band is first modulated with a carrier of frequency c, and the upper sideband, extending from (c + a) to (c + b) is selected. This band is then modulated with a carrier of frequency (c + a + b), and the lower sideband is selected. This sideband occupies the band [(c + a + b) — (c + a)] to [(c + a + b) — (c + b)] i.e., b to a, and is inverted with respect to the original band. Any direct leak through the modulator is now of little importance and can be filtered out, since it falls outside the frequency ranges occupied by the band during the process of inversion.

Modulators.

So far the assumption has been made that a modulator is available in which a signal of frequency a, modulated with a carrier of frequency c, gives rise to modulation products of (c ± a), and no others.

The ring modulator[3] approaches the ideal. An ideal ring modulator, when supplied with a carrier of frequency c, and input of frequency a, would produce in its output components of frequencies [(2n + 1) c ± a], where n is an integer. The energy of each of these components would be proportional to $1/(2n + 1)^2$. Since a practical ring modulator is not ideal, other intermodulation products will be present in the modulator output. These components have frequencies of [(2n + 1) c ± ma] and [2nc ± ma], m and n being integers. Any of these may overlap the [(2n + 1)c ± a] components and thus cause intermodulation crosstalk. This deviation from the ideal modulator is due partly to the non-linearity of the rectifier characteristics and partly to impedance unbalance in the modulator network. The most serious of the unwanted components are those with frequencies of (2nc ± ma), the (2c ± a) components having the highest energy of the series. If, however, the carrier frequency is more than double the highest input frequency the (2c ± a) components will lie outside the frequency range occupied by the required components (c ± a).

[1] *P.O.E.E.J.*, Vol. 29, p. 220.
[2] *P.O.E.E.J.*, Vol. 32, p. 52.
[3] *P.O.E.E.J.*, Vol. 29, p. 294.

The energy in the remaining unwanted components can be kept low by using a high carrier power and a low input signal power. An investigation into the problem of ring modulators has shown that copper oxide rectifier units can be used up to frequencies of at least 300 kc/s, and that, if the level difference between carrier and input energies is 20 db. or more, the unwanted components are at least 70 db. below the chief components (c ± a). Such a modulator was first used by the Post Office as a group modulator in the equipment installed on the Stranraer-Belfast carrier route.[4] An improved form of modulator is now available which, including input and output transformers, rectifier network and attentuating pads, can be accommodated in a transformer pot. Fig. 2 shows one such modulator unit, the photograph being of a unit used in the experimental group inverter.

Carrier Frequencies.

The lowest carrier frequencies which could be used, i.e. c and (c + a + b), were 120 kc/s and 192 kc/s. A more suitable pair of frequencies, however, are 144 and 216 kc/s. These are both harmonics of 72 kc/s (and 36 kc/s) so that they may be obtained by a frequency multiplying circuit, from the carrier supplies at stations equipped with Carrier System No. 5 or No. 7. At a Carrier System No. 6 terminal, a 72 kc/s supply may be obtained either by direct multiplication of the 6 kc/s supply which is available, or by the addition of the frequencies of two suitable carrier supplies, by means of a modulator circuit.

Design of Filters.

To select the required sideband after the first modulation a band-pass filter is used. This filter has to pass a band extending from (144 + 12) kc/s (i.e., 156 kc/s) to (144 + 60) kc/s (i.e., 204 kc/s) and to offer a certain minimum attenuation to frequencies outside this band (see Fig. 3). The filter attenuation requirements are that the unwanted sidebands must be attenuated by at least 30 db., and any direct leak through the first modulator by at least 60 db. This last requirement ensures that, if both modulators in one path are badly out of balance, the direct leak from input to output shall be at least 80 db. below the wanted signal output. A band pass filter of two sections, one section having peak attenuations at 219 kc/s and 145 kc/s and the other section being of constant — k type, meets these requirements.

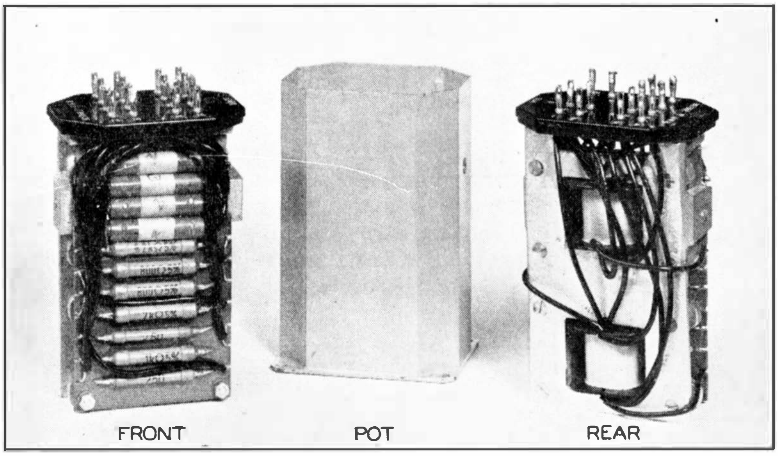

Fig. 2.—Frequency Changer Assembly.

The filter following the second modulator is of a simple low-pass type, passing frequencies up to 60 kc/s.

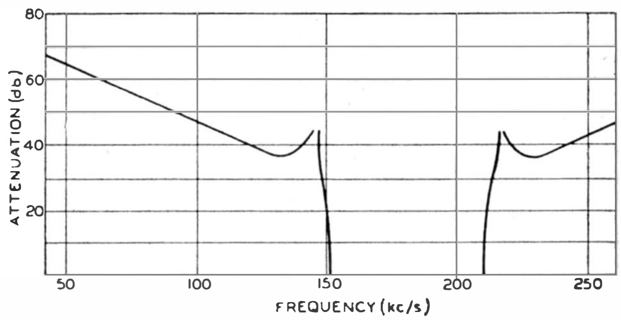

Fig. 3.—Insertion Loss of Band-Pass Filter in 600 Ω Circuit.

[4] *P.O.E.E.J.*, Vol. 32, p. 112.

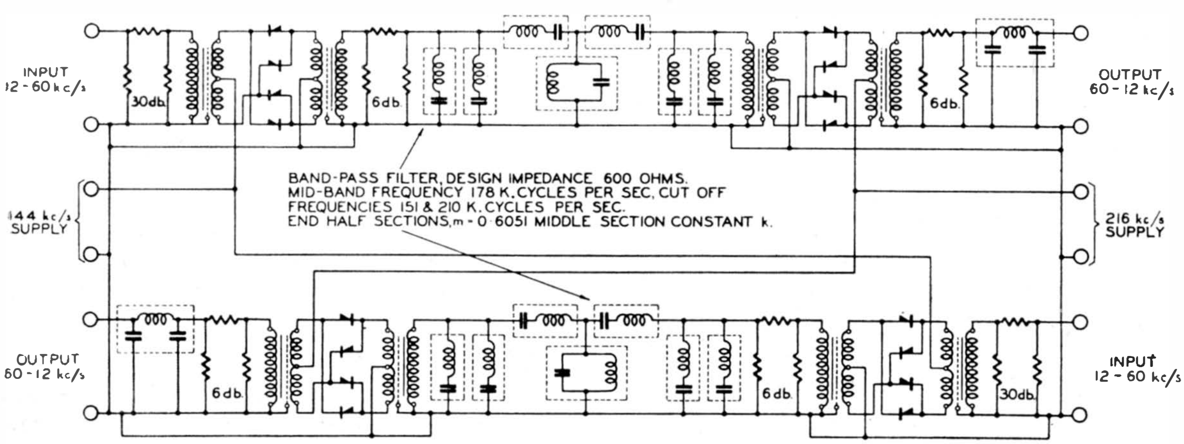

Fig. 4.—Circuit of Group Inverter.

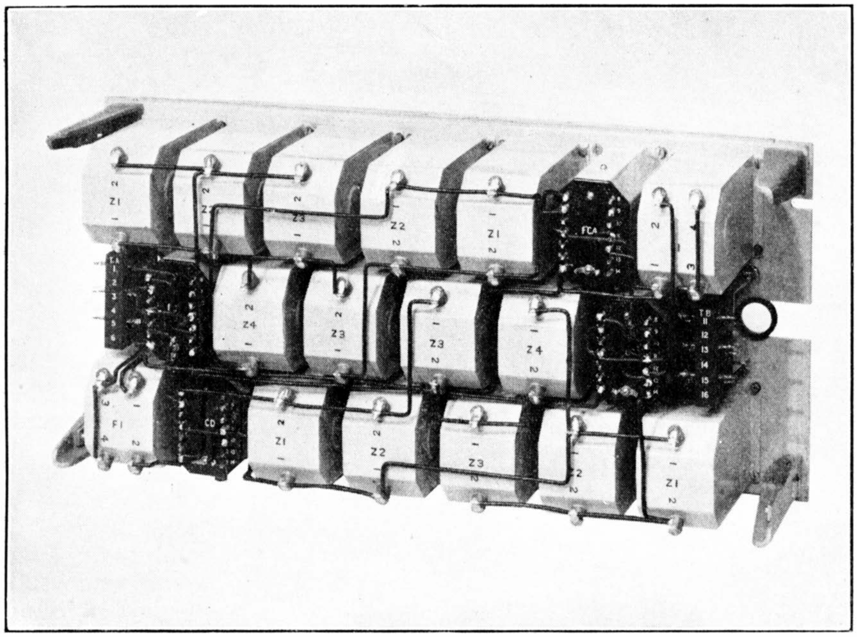

FIG. 5.—GROUP INVERTER.

Design of Complete Modulator.

Fig. 4 shows the circuit arrangement of the experimental unit. Two inverters are provided, one for each direction of transmission. The inverter is inserted in a circuit at a point of + 5 db. relative level, and the loss through the unit is compensated by two line amplifiers, one for each direction of transmission. A 30 db. attenuator reduces the input signal to a relative level of — 25 db. before it is applied to the first modulator, which is fed with a carrier of frequency 144 kc/s. The output from the first modulator then passes through the band-pass filter, where the band 156 to 204 kc/s is selected. This is then applied to the second modulator, the carrier frequency of which is 216 kc/s. The output from this is passed through a low-pass filter which passes the band 12 to 60 kc/s. A 12-circuit line-amplifier then raises the relative level of the signal to be equal to that at the input to the inverter. A similar process occurs in the other half of the inverter, which is used for the return direction of the 12-circuit group.

Fig. 5 shows a model group inverter which was constructed to the design outlined above. It is mounted on a standard repeater rack panel 19 in. × $8\frac{3}{4}$ in.

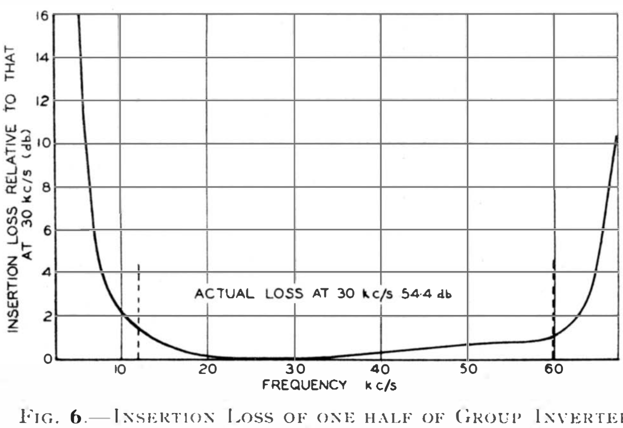

FIG. 6.—INSERTION LOSS OF ONE HALF OF GROUP INVERTER IN 600Ω CIRCUIT.

Tests on Group Inverter.

Performance tests have been made on the inverter. Fig. 6 shows the response, from input to output, of one half of the inverter. It will be seen that the response is flat to within ± 0·75 db. over the required transmission range of 12 to 60 kc/s.

The two halves of the inverter, together with two line amplifiers were then set up, so that a circuit of zero loss, including two inversions, was obtained. This was connected in the common path of a 12-circuit system, at a point of + 5 db. relative level. The specification test of two speakers at Reference Telephonic Power was then applied to the system, and psophometric noise E.M.F.'s were measured on the remaining channels. The channels chosen were those on which the worst values of noise voltage might be expected. The results are shown in Table I.

TABLE I

Intermodulation noise voltages (psophometric mV E.M.F. at zero level points) due to both halves of inverter.

Talkers on Channels.	Measured on Channels.	mV.
8 and 12	1	0·56
2 and 6	1	0·48
2 and 11	1	0·36
5 and 9	1	1·20
1 and 2	6	0·56
3 and 12	6	0·56
9 and 12	6	0·69
4 and 5	6	1·89
4 and 5	12	0·48
1 and 8	12	1·00
1 and 5	12	0·89
8 and 10	12	0·48

These are all less than the maximum of 2mV E.M.F. specified by the Post Office, and are due to intermodulation in the 12-circuit system, the two halves of the group inverter and two line amplifiers. In normal use only one inverter will be in circuit, and the noise voltages will be less than those observed.

These results are considered to be satisfactory, since the use of such a group-inverter will not seriously degrade the transmission of any system into which it may be connected. The production model of the inverter, for use on the 12-circuit carrier trunk system, is at present being developed in conjunction with contractors and will be described in a later article.

Noise-Eliminating Unit for Junction Circuits Exposed to Power Induction

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U.D.C. 621.395.8 621.395.332.2 : 621.396.662.3

Simple apparatus is described which may be associated with a junction to reduce the amount of noise due to power induction when other methods have proved ineffective. The loss introduced is less than 0.5 db. per unit, and the addition to the ohmic resistance of each leg of the junction is 20 ohms at each end.

Introduction.

WHEN an overhead telephone pair runs for a considerable distance in close proximity to an overhead power transmission line or electrified railway, a longitudinal noise E.M.F. is induced in each wire of the telephone pair. If the E.M.F.'s induced in the two wires were precisely the same, and if all lines and apparatus connected to their ends were perfectly symmetrical with respect to earth, no noise P.D. would exist between the A and B legs of the circuit at any point, though at most points both wires would be at a noise P.D. with respect to earth. The loop circuit would therefore be free of noise.

In practice these ideal conditions do not obtain, and a junction circuit containing an overhead section exposed to power induction may be noisy due to one or more of the following causes :—

(1) Asymmetry of the two overhead wires with respect to the source of induction, so that the longitudinal E.M.F.'s are unequal, and a resultant E.M.F. is induced into the loop circuit. This effect is usually of importance only when the separation of the telephone and power lines is small, and is reduced by suitable transposition of the telephone conductors within the section in which the induction is taking place. If the power line contains transpositions within the same section it may be necessary to co-ordinate the telephone circuit transpositions with these.

(2) Even when the conditions are such that the longitudinal E.M.F.'s in the two telephone conductors are equal, a noise P.D. between the conductors may arise due to :—

(*a*) Asymmetry or unbalance of the A and B lines with respect to earth, as regards their series impedance, capacitance or leakance.

(*b*) Asymmetry of the terminal equipment with respect to earth.

Careful attention to line maintenance mitigates trouble due to (*a*), though the standard of maintenance required may often be higher than that found sufficient on junctions not exposed to power induction. With British junction lines (*b*) is the commonest cause of noise.

The equipment connected to junction lines in most types of exchanges is nominally balanced to earth, but the limits of unbalance are determined by what is commercially practicable without undue increase in cost. These limits are quite satisfactory for normal junction lines, but a much higher degree of balance is required on lines exposed to severe power induction. The most obvious solution is to select or construct specially balanced components for these junctions. Unfortunately the particular items of exchange apparatus connected to a junction circuit may vary, depending, for example, on which of a number of selectors happens to be idle at the time the call is set up. In such circumstances it would be necessary to equip an appreciable proportion of the exchange apparatus with specially balanced components. Furthermore, a call may be routed to a second exchange and noise may be produced unless the equipment at this exchange is also highly balanced. It is evident that it would be necessary to make a special study of all possible call routings in each particular case, and the large amount of non-standard equipment and consequent high cost and loss of interchangeability render the solution impracticable.

An alternative solution, which forms the subject of this article, consists in inserting at each end of the junction a unit which provides high attenuation to longitudinal voltages, while transmitting loop circuit voltages with very little loss. The longitudinal noise voltage applied to the exchange equipment is consequently very small, and a high degree of balance is no longer necessary.

Basic Circuit.

The basic circuit of the unit is shown in Fig. **1**. It consist of a 1 : 1 transformer T which transmits the loop (i.e., speech) currents. Both primary and

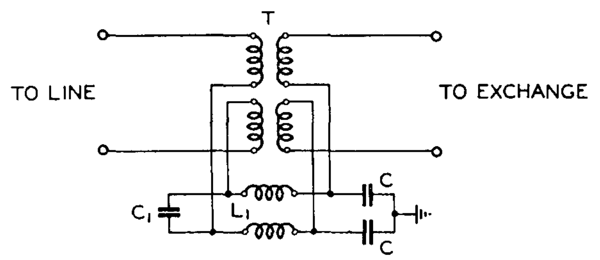

Fig. **1**.—Basic Circuit.

secondary windings are split, the inner ends being connected by the two windings of the inductance coil L_1. Equal longitudinal currents (i.e., currents in the same direction in the A and B legs of the circuit) in the two halves of the primary winding mutually cancel and produce no E.M.F. in the secondary windings. For loop currents the condenser C_1 completes the primary circuit, and the two condensers CC in series complete the secondary circuit. It will be seen that the continuity of the A and B legs of the circuit remains uninterrupted, so that, provided the resistance added to the circuit is small, normal signalling methods will be possible. The windings of the inductance L_1 are magnetically

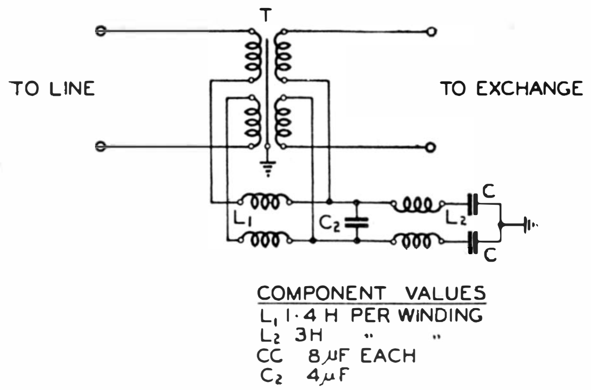

FIG. 2.—CIRCUIT DIAGRAM OF FILTER UNIT.

additive for longitudinal currents. This inductance, in conjunction with the condensers CC, forms a low-pass filter for longitudinal voltages.

Performance Requirements.

The filter unit should fulfil the following requirements :—

(1) The balance to earth of the unit must be of a much higher order than that of the exchange equipment, otherwise the improvement will be small.

(2) The units should not add more than about 40 ohms to the resistance of each leg of the circuit in order that the normal signalling may not be appreciably affected even on long junctions. As there will normally be one unit at each end of the junction, each unit should not add more than 20 ohms to each leg.

(3) The insertion loss of the unit to longitudinal voltages should be adequate for all values of longitudinal impedance of lines and of exchange equipment likely to occur.

(4) The filter unit should not, in conjunction with the exchange equipment, resonate at 50 c/s. 50 c/s induction is not likely to be troublesome from a noise standpoint, but if accentuated by resonance may become of sufficient magnitude to cause chattering of relays.

(5) The insertion loss to speech currents should not exceed about 0·5 db. per unit.

Circuit Design.

Transformers and chokes to satisfy requirements (1) and (5) can be constructed without difficulty. Requirements (3) and (4) necessitate the use of filter condensers of not less than 8 μF. The cost and bulk of mica dielectric condensers would be prohibitive, and the required degree of balance could not be reliably maintained with paper dielectric condensers. The modified circuit of Fig. 2 was therefore adopted. A second two-winding inductance L_2 and an additional condenser C_2 are added, the connections to the windings of L_2 being in the reverse sense to the connections to L_1, i.e., they are magnetically additive for loop currents. In conjunction with C_2 the inductance L_2 forms a low-pass filter for any loop voltage generated by unbalance of the condensers CC. The unbalance voltage reaching the output terminals to the line or exchange is therefore negligible even when the unbalance of these condensers is as high as 10 per cent., and standard paper dielectric condensers can consequently be used. L_2 is non-inductive to longitudinal currents, so that provided its resistance is small, its effect on the longitudinal attenuation of the filter is negligible. Similarly, the impedance of L_1 to loop currents is very small, so that the condenser C_1 can be omitted, condenser C_2 completing both primary and secondary circuits of the transformer. The circuit and values of Fig. 2 should satisfy requirement (3). However, the design of inductance L_1 is influenced by the particular combination of exchanges terminating the junction. The core of L_1 is magnetised by the algebraic sum of the direct currents in the A and B legs. With exchanges of modern design, these currents, under speaking conditions, are nominally equal and in opposite directions. The magnetising effect on the core is therefore merely that caused by the unbalance of the two currents due to tolerances on the resistance of relays and differences between exchange battery voltages. A suitable inductance can then be constructed on a small standard core. The complete filter, which is mounted on a standard relay mounting strip, is shown in Fig. 3. With certain older types of exchange, the currents in the A and B legs under speaking conditions are in the same direction. The magnetising effect on the core of L_1 is therefore considerable, and a larger non-standard core is necessary to avoid saturation. The layout of the filter employing the larger inductance coil is shown in Fig. 4. Two standard relay mounting strips accommodate two filter units. This layout is less convenient than that of Fig. 3, but it may be possible, in course of time, to abandon it, as the exchanges requiring the larger coil are obsolescent. Figs. 3 and 4 show the normal layouts of the two types of filter ; the type of mounting used in some exchanges necessitates a slight modification in the arrangement of the components.

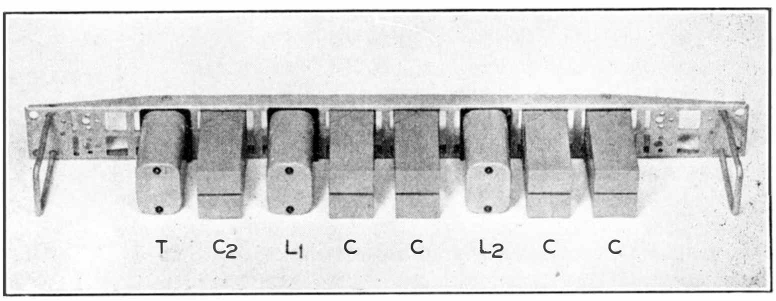

FIG. 3.—NOISE-ELIMINATING FILTER UNIT.

The circuit of Fig. 2 presents a high longitudinal impedance to the line and a low longitudinal impedance to the exchange equipment. As the longitudinal impedance of the exchange equipment is usually greater than that of the line, this arrangement provides, in general, the highest attenuation for longitudinal voltages. However, on certain junction routes, where it is difficult to maintain a high standard

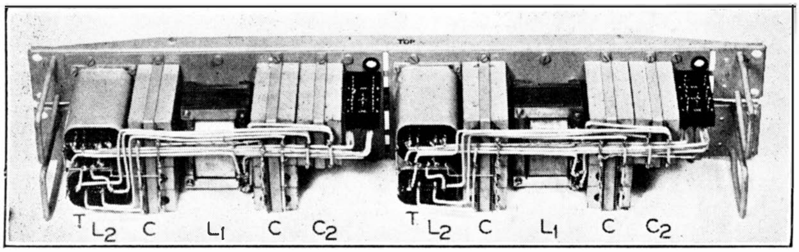

FIG. 4.—NOISE-ELIMINATING FILTER UNIT FOR SPECIAL CASES.

of leakance balance of the line, a filter presenting a low longitudinal impedance to the line may be preferable. The longitudinal noise voltage on the line is thereby reduced, and consequently also the loop voltage resulting from a given amount of leakance unbalance. The longitudinal noise current is, however, increased, so that the loop voltage resulting from a given amount of line resistance unbalance will be greater, but this type of unbalance can, in the circumstances assumed, be more readily kept small. A filter having the required impedance characteristic can be produced by interchanging the line and exchange connections to the unit of Fig. **2**. If this results in insufficient longitudinal attenuation, the original connections may be retained, and a second inductance L'_2 with associated condensers C'_2 and

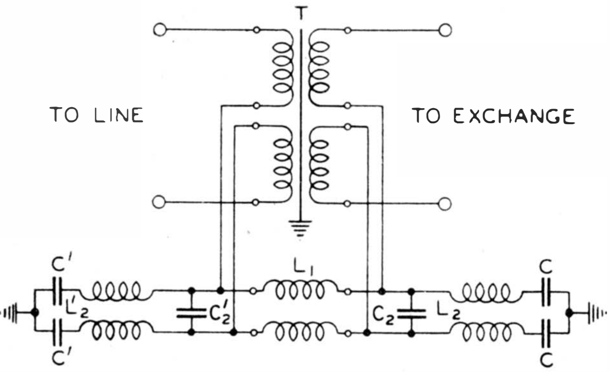

FIG. **5**.—MODIFIED CIRCUIT FOR JUNCTION LINES HAVING HIGH LEAKANCE UNBALANCE.

C′C′ connected to the line ends of L_1. The modified circuit is shown in Fig. **5**. This modification would only rarely be required and the extra components would be added as an auxiliary unit.

Performance.

The insertion loss of the unit to longitudinal voltages depends partly on the longitudinal impedances of the line and exchange equipment; Fig. **6** shows the approximate variation of the longitudinal attenuation with the frequency of the induced noise. The attenuation is so large that with the units the noise on a circuit will normally be only that due to line unbalances.

Practical Application.

When the units are applied to a junction between manual exchanges, they may be connected permanently in circuit, since signalling currents are transmitted normally. Dialling impulses, however, would suffer excessive distortion if transmitted through the units. On junctions over which it is necessary to transmit dialling impulses, therefore, switching relays must be provided which remove the units from the circuit during the dialling period. Usually it will be convenient to arrange the switching so that the units are normally out of the line circuit, and are switched in when the called subscriber answers. The scheme has the disadvantage, however, that the noise is present during the whole of the time while the call is being set up, and it tends to mask the supervisory tones.

The units cannot be regarded as a panacea for all line noise troubles. As already indicated, their primary function is to reduce the effect of unbalances in the exchange equipment terminating the junction, though they may modify the effect of line unbalances. It should be remembered that the space taken up by the units, the increased fault liability due to the additional apparatus, the inconvenience of having a few non-standard junctions, and the necessity of maintaining a very high degree of balance on the line, are all formidable disadvantages. If the noise can conveniently be reduced by measures applied to the power system, or by re-routing the telephone lines, these remedies may often be preferable.

A rough test to determine whether the units are likely to prove an effective remedy in any particular instance can be made by isolating the junction from the exchange apparatus at both ends, and terminating it at one end with a telephone receiver, and at the other with a resistance of about 600 ohms. If the noise in the receiver is then very much less than the noise heard during an average normal call set up over the junction, the filter units will probably be effective. If, on the other hand, the noise is still considerable, an attempt should be made to improve

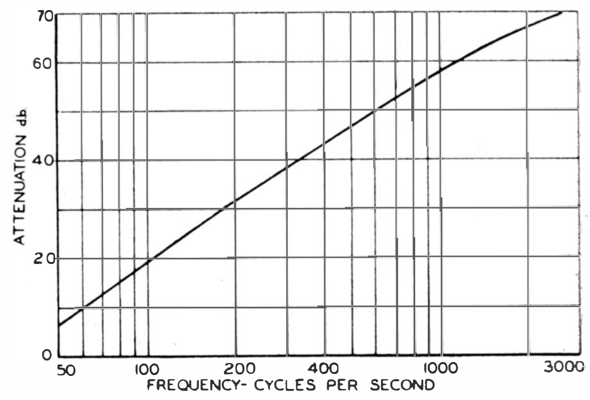

FIG. **6**.—LONGITUDINAL ATTENUATION OF UNIT.

the balance of the line or the transposition scheme, or both. The listening tests should then be repeated, and will show whether the measures have been effective in reducing line unbalances, and whether units are required in addition.

Modern Materials in Telecommunications

U.D.C. 539 669

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Part III.—The Nature of Metals and Alloys

This article deals with the structures of metals and alloys and shows how they are related to mechanical properties. The relation is illustrated by reference to certain new non-ferrous alloys of possible interest to telecommunications engineers.

Crystallinity of Metals.

At first sight a piece of metal would appear to be a homogeneous material such as glass. In reality, however, metals are crystalline, and in the ordinary course of events consist of an agglomeration of crystals. This is illustrated in Fig. 1, which is a photomicrograph of a piece of polished and etched lead.

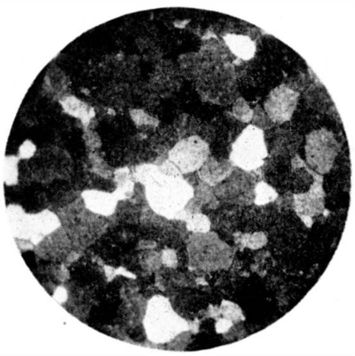


Fig. 1.—Photomicrograph of Lead illustrating Crystalline Nature of Metals. Mag. × 5.

Metals crystallise in three out of the known six crystalline systems. In Table 1 are set out some of the more common metals used in communications engineering, together with their respective crystalline forms. Reference to Fig. 2 will explain the meaning of the terms employed in naming each crystal system.

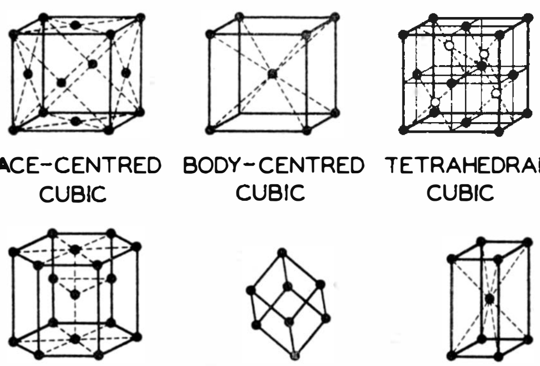


Fig. 2.—Typical Crystal Units.

Table 1.

Crystal System	Metals
Cubic, face-centred ..	Nickel, Copper, Silver, Platinum, Gold, Lead, Aluminium, γ-iron and β-cobalt.
Cubic, body-centred ..	Tungsten, α-iron and α-chromium.
Cubic, tetrahedral ..	α-tin.
Hexagonal, close-packed	Zinc, Cadmium, β-chromium and α-cobalt.
Hexagonal, rhombohedral	Antimony.
Tetragonal	β-tin.

The above table shows that most metals crystallise according to the cubic system. It will be recollected from the first article that the dimensions of the crystal unit are of the order of 3 to 6 Angström units (3 to 6×10^{-8} cm.), and each crystal contains many millions of such patterns. Furthermore, except in some circumstances, there are many thousands of crystals to each cubic centimetre.

Of course, the conception of an atom taking the form of a sphere, as shown in Fig. 2, is not correct; it is employed only to enable a visual picture to be obtained of the atomic arrangement within a crystal. As was pointed out in the first article of this series, physicists have shown that the atom is composed of a composite nucleus surrounded by shells of electrons. These components, together with the arrangement of the atoms in the crystal unit, are ultimately responsible for a large number of the properties exhibited by metals and alloys. For example, atoms are held in position in the crystal unit by interatomic forces, which differ in degree according to the metal. When a stress is applied, these forces tend to oppose deformation caused thereby, and thus they are to a considerable extent responsible for the mechanical properties possessed by metals.

Alloying.

In the search for improved metallic materials, the task of the metallurgist is to discover new intimate mixtures of two or more metals which, when cast or submitted to heat treatment or mechanical working, will possess the properties desired. Such intimate mixtures are called alloys.

Disregarding alloying by powder metallurgy methods, the first requisite for the successful alloying of metals is that they should be soluble in each other when in the molten state.

Very little is known of the mechanism concerning the solubility of metals in each other when molten, but considerable information is available concerning the phenomenon of solid solubility. In effect, when two metals are said to be mutually soluble in the solid state this means that atoms of the solute metal are able to enter the crystal unit of the solvent metal. This they can do in one of two ways. Firstly, atoms of the solute may replace those of the solvent, in which event the resulting solid solution is described as substitutional. Secondly, the solute atoms may enter the crystal unit of the solvent by taking up positions in between the atoms in this crystal unit. A solid solution so formed is called interstitial. The appearance of the crystal unit with atoms incorporated substitutionally and interstitially is shown in Fig. 3.

Actually very few metals dissolve in each other in the interstitial way because their atoms are too big, but many non-metallic elements dissolve in metals in

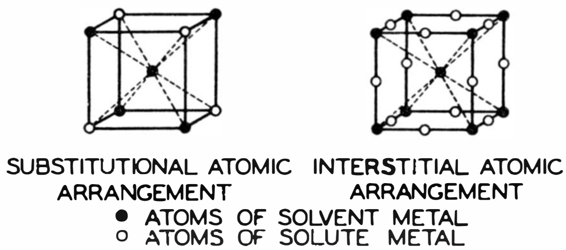


FIG. 3.

this manner. For example, carbon enters the crystal unit of iron interstitially to form the hardening constituent of steel.

When an alloy solidifies the component metals may (1) remain in solution, i.e. form a solid solution; (2) precipitate as a mechanical mixture of the pure metals, or more often as a mechanical mixture of the metals with a little of the others dissolved in each to form a eutectiferous alloy; (3) form intermetallic compounds; and (4) form a mixture of a solid solution and a precipitated intermetallic compound. The appearance under the microscope of the first two and last of these types is shown in Fig. 4.

Examples of some materials used in communications engineering which solidify in these different ways are given in Table 2.

TABLE 2.

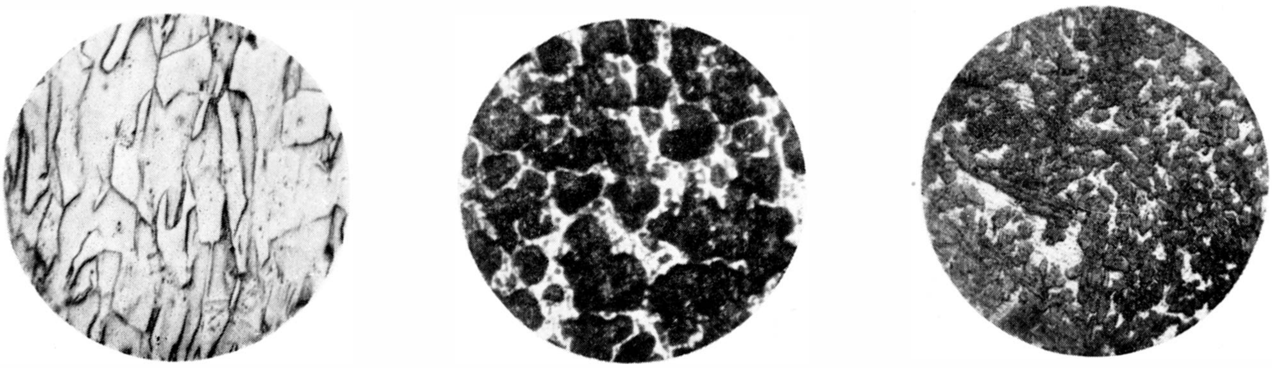
Type of Solidification	Material
Solid solution alloy	Nickel silver for relay springs, nickel-iron alloys of the Permalloy type, phosphor bronze and brass for springs and cadmium-copper for overhead line wire.
Eutectiferous alloy	Solder, silicon-aluminium alloy for insulating gap castings, and antimony-lead alloys for battery plates.
Intermetallic compound alloy	There are none, because alloys consisting only of an intermetallic compound are brittle, but brass for castings contain an intermetallic compound in their structure.
Solid solution and intermetallic compound alloy	Most steels, bronze alloys for castings, magnetic alloys of the Alni and Alnico types.

Factors affecting Solid Solubility.

From what has been said above concerning the different ways in which metals solidify from the molten state, it will have been gathered that some metals show greater mutual solid solubility than others, and that some are capable of forming intermetallic compounds. The question may well be asked : Why should this be so? Again, why is it that temperature has so considerable an effect on the mutual solid solubility of some metals? These facts are of great interest and importance, not only from the purely scientific point of view, but also because they are largely responsible for the improved properties obtainable from alloys on heat-treatment.

Until comparatively recently the factors affecting the mutual solid solubility of metals have been very incompletely understood. The latest and most promising theories to take account of these factors have been put forward by Hume-Rothery. These theories are described in his book, " The Structure of Metals and Alloys." In discussing here the phenomenon of mutual solid solubility of metals, it is proposed to confine the remarks to a very brief outline of Hume-Rothery's theories.

The most important factor affecting the degree of solid solubility of one metal in another is the relative



(*a*) (*b*) (*c*)

FIG. 4.—PHOTOMICROGRAPHS OF (*a*) NICKEL-SILVER, A TYPICAL SOLID SOLUTION ALLOY; (*b*) PLUMBER'S SOLDER SHOWING MECHANICAL MIXING OF THE TWO METALS IN THE ALLOY; AND (*c*) A SHOT-WORKING BRASS ILLUSTRATIVE OF A STRUCTURE CONTAINING A SOLID SOLUTION (LIGHT SHADE) AND INTERMETALLIC COMPOUND (DARK SHADE). MAG. (*a*) × 180, (*b*) × 180 AND (*c*) × 140.

size of the atoms of the solute and solvent metals. This can be readily understood when it is remembered that the atoms in a metal crystal take up regular positions in space, the arrangement, unlike the picture presented in Fig. **2**, being closely packed. Thus, if the atomic diameter of the solute atom is large compared with that of the solvent atom, the former will not be able to enter so freely the crystal unit of the solvent metal. In the same way, of course, is the converse of this true. It should be made clear, however, that these facts do not represent quite the whole story, for the atomic diameters of the atoms of some metals change when they enter the crystal unit of certain others.

Although the "size-factor" of atoms indicates which metals are likely to show considerable mutual solid solubility, there are several other factors which have to be taken into account. The first of these is the tendency of certain pairs of metals to form intermetallic compounds, by which is meant that a definite number of atoms of each metal combine to form a molecule, which henceforth exists as a unit and must be accommodated in the crystal unit as such.

Even supposing the relative size of solvent and solute atoms is favourable and no intermetallic compounds are formed, there is still one other factor which limits the extent of solid solubility of one metal in another. This factor is the question of valency, or the combining power of the atoms of any particular element (see Part II, p. 127). It has been found, for example, that the greatest solid solubility between metals is obtained when they have the same valency.

Changes in Mutual Solid Solubility of Two or More Metals.

The mutual solid solubility of some metals increases with a rise in temperature. The reason for this is that a rise in temperature produces greater atomic mobility which allows more atoms of the solute metal to pass into the crystal unit of that forming the solvent. This phenomenon, as will be explained later, is fundamentally responsible for the process of age-hardening, which can be employed for improving the mechanical properties of certain alloys, particularly those of aluminium.

HEAT-TREATMENT.

Heat-treatment, which enables metals and alloys to be put in the most suitable condition for certain uses, has always been a very important operation in metallurgy. Of more recent years it has become of even greater importance, owing to the fact that many new alloys rely on heat-treatment for the full development of their mechanical, electrical and magnetic properties and their resistance to corrosion.

It will have been gathered that—in popular language—the higher the temperature the more loosely are atoms held in the crystal unit, and the more easily can the entire crystal unit be adjusted to accommodate external deformation of the material. In practice heat-treatment is, therefore, utilised to relieve internal stress caused by previous mechanical working, or to render the metal or alloy more plastic for further working. Heat-treatment is also employed to make use of the changes in crystal structure which take place in some alloys when they are heated above certain temperatures while in the solid state. On controlling such changes, by cooling at the critical rate, improved mechanical and other properties may be obtained.

The Utilisation of Changes in Crystal Structure which take place in some Alloys while they are in the Solid State.

The fact that changes in crystal structure can, under suitable conditions, take place in certain alloys while they are in the solid state is made use of extensively in commercial practice. Most of these changes result from (1) allotropic transformations, (2) changes in mutual solid solubility of the metals composing the alloy, (3) formation and decomposition of intermetallic compounds, and (4) "order→disorder" phenomena. Of these the first is familiar by reason of the part it plays in the hardening of steel, and the third is not of first importance to commercially used alloys, so that the second and fourth will be discussed.

Heat-treatment Based on a Change in Mutual Solid Solubility of the Metals composing an Alloy.

When two metals are more soluble in each other at raised temperatures than at normal temperatures, then by suitable heat-treatment, which is referred to variously as age-hardening, precipitation-hardening or dispersion-hardening, it is very often possible greatly to improve the properties of the resulting alloy.

As an illustration of the age-hardening process, the aluminium alloy duralumin may be considered. This alloy contains two intermetallic compounds, magnesium silicide (Mg_2Si) and copper aluminide ($CuAl_2$). It is the increase with temperature of the solid solubility of these two constituents in aluminium which is fundamentally responsible for the age-hardening of duralumin. The manner in which this is brought about can best be described in the following way. On slowly cooling duralumin from the molten state, the alloy consists immediately on solidification of a solid solution of $CuAl_2$ and Mg_2Si in aluminium. On further cooling, however, owing to the decrease in the solid solubility of $CuAl_2$ and Mg_2Si in aluminium with decrease in temperature, the face-centred cubic lattice of aluminium becomes saturated with the two intermetallic compounds at a temperature of about 450°C. At this temperature, therefore, the constituents $CuAl_2$ and Mg_2Si come out of solution to some extent, with the result that there exist in duralumin these two intermetallic compounds with the primary solid solution, which structure persists down to room temperatures. Now, it so happens that if duralumin is heated to a temperature just over that at which the maximum solid solubility of $CuAl_2$ and Mg_2Si in aluminium is obtained, i.e. about 500°C, and then quenched in cold water, the solid solution stable at the higher temperature can be retained temporarily at normal temperatures. In this condition the duralumin is in a very soft state and can easily be cold worked. Cold working cannot readily be done for long after quenching, however, since, owing to the instability of the retained solid solution, precipitation of the two intermetallic compounds in a finely dispersed state takes place, which is accompanied by hardening of the alloy. At one time it was thought that this precipitation was itself responsible for age-hardening, it being postulated that the finely dispersed particles lodged themselves on the planes of slip in the crystals, thus making slip less easy when a stress is applied, consequently increasing the strength of the alloy. Of more recent years, however, it has been established that age-hardening takes place before precipitation of the particles of $CuAl_2$ and Mg_2Si has actually occurred. It therefore seems that some rearrangement of the atoms of the solid solution must be responsible for the phenomenon of age-hardening. The precise form this rearrangement takes, however, has not yet been discovered. It is thought probable that whatever structural change occurs it is bound up with the question of crystal slip being made less easy. The significance of crystal slip in relation to the strength of metals will be discussed in the next section but one.

Order→Disorder Phenomena.

The solution of one metal in another, either substitutionally or interstitially can take place either in a regular or haphazard fashion. The resulting crystal units are known as ordered and disordered structures respectively. Examples of the two types of structure are shown in Fig. 5. In some solid solutions, however, the crystal unit can exist in the ordered or disordered

Fig. 5.

state according to the heat-treatment the alloy has received, the former crystal unit being that type stable at normal temperatures. Thus on heating such a solid solution above a certain temperature, disorder sets in, slowly at first but later quite rapidly. The rapid change does not take place until what might be termed the "critical temperature" is reached. This critical temperature, however, cannot be considered in the same light as a critical temperature of an allotropic transformation since the order→disorder change takes place over a range of temperature. By quenching from a temperature at which the crystal unit is completely disordered, this structure may be retained at normal temperatures.

The order→disorder change is one of the more recently discovered phenomena exhibited by alloys in the solid state. It is accompanied by changes in mechanical and physical properties. One theory to explain the beneficial effects the heat-treatment of the nickel-iron alloys has on their magnetic properties asserts that an order→disorder change is responsible.

Mechanical Properties of Metals and Alloys.

The mechanical properties of metals and alloys are fundamentally dependent upon the nature of the atoms of which they are composed and upon the way in which these atoms are arranged in the crystal unit. Thus hardness and strength are mainly functions of the forces existing between the atoms, whereas ductility is chiefly related to the type of crystal unit in which the atoms are held in space. As an illustration of the latter relationship, the metals nickel, aluminium, lead, copper, iron, zinc, cadmium and magnesium may be considered. The first four of these metals, which are well known for their good ductility, crystallise in the face-centred cubic system. Iron at ordinary temperatures exists in the body-centred cubic form and is less ductile; the last three metals, which belong to the hexagonal crystal system, exhibit only moderate ductility.

But besides the importance of the forces between metallic atoms and their arrangement within the crystal structure, the micro-structure (i.e. the crystal formation as seen under the microscope) may also profoundly affect the mechanical properties of metals and alloys. For example, cuprous oxide, which is practically insoluble in copper, if present to an extent greater than about 0·1 per cent., renders the metal brittle. This is because it tends to segregate to the crystal boundaries and, being a brittle material itself, imparts this property to the copper.

When two or more metals are alloyed, the resulting alloy may have poorer or better mechanical properties than those of the individual metals. If the metals form an alloy of the type where there is little or practically no mutual solid solubility, then improvement or otherwise in mechanical properties follows the general laws appertaining to aggregates. If, on the other hand, the metals form an alloy of the solid solution type, the change in mechanical properties is essentially due to the entry of the atoms of the added metal into the crystal unit of the basis metal causing a distortion of the atomic arrangement of the latter and perhaps the formation of an additional solid solution. Distortion of the crystal unit of a metal makes slip within the crystals more difficult, consequently raising their resistance to deformation. The distortion of a crystal unit by the entry of other atoms is shown in Fig. 6. But distortion of the crystal unit

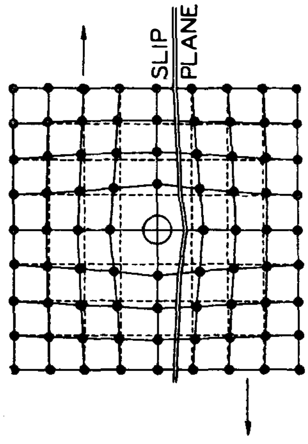


Fig. 6.—Distortion of Crystal Unit by Entry of Solute Atoms.

brought about in this way has comparatively little direct effect on mechanical properties. What is more important is the result the alloying has on the capacity of the alloy to benefit from mechanical working or heat-treatment operations. Similarly, although the nature of the atoms and the way in which they are arranged in space are fundamentally responsible for the mechanical properties of pure metals, it is the extent these attributes enable advantage to be taken of working and heat-treatment operations which is of the greater importance in the development of mechanical properties.

The Development of Mechanical Properties by Mechanical Working Operations.

There are two general forms of mechanical working operations : (1) hot working, and (2) cold working. Hot working develops mechanical properties only in so far as it homogenises and refines the crystal size of a metal or alloy. Homogenising, especially with an alloy, has the effect of evenly distributing the various constituents, thereby rendering the alloy equally strong throughout its mass. Refinement of crystal size is of importance because a coarse crystal structure usually makes a metal weak with poor ductility. With cold working operations, however, the effects on mechanical properties are very much greater, and to understand just why this should be so, some consideration must be given to the deformation of metals and alloys by cold work.

When a metal or alloy is plastically deformed in the cold, i.e. when the elastic limit has been passed, it can be shown by microscopic or X-ray examination that slip takes place within the crystals along certain crystallographic planes. This is shown diagrammatically in Fig. **7**. On account of this there is relative movement between component parts of

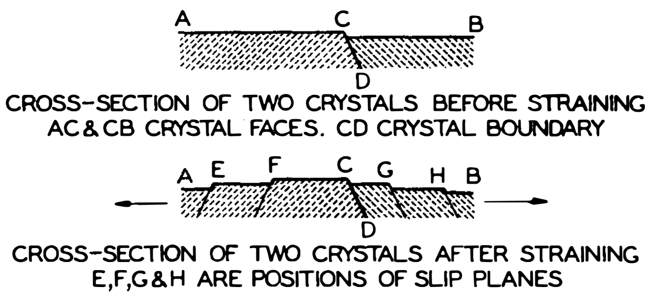


FIG. 7.—FORMATION OF SLIP BANDS.

the crystal, which may be likened to the movement over one another of cards in a pack. This process, coupled with the restraining effect of the crystal boundaries, tends to elongate the crystals in the direction of the application of stress. During the process of slip there is a rearrangement of the atoms within the crystals. Since the orientation of the crystals in an unstrained metal or alloy is at random, it follows that slip must take place as a result of shearing action. As was stated previously, slip takes place along crystallographic planes. Along some of these it is easier for slip to occur than along others. After a certain amount of movement has taken place on any particular set of slip planes, it ceases, and is followed by a movement on other planes. Just what is responsible for this cessation of slip is not known precisely, although it is thought that the crystal boundaries play a not unimportant part in acting as a kind of buffer. Ultimate fracture does not take place on the planes of original slip, but on those where slip has most recently occurred. As the process of slip proceeds, the axes of individual crystal units swing round so that the whole of the crystals become re-orientated in the direction of the application of stress. Such a condition is known as " preferred orientation."

Evidence of this is obtained from X-ray diffraction patterns as shown in Fig. **5** of the first article.

Now the point about crystal slip, as it affects the mechanical properties of metals and alloys, is that the process places the atoms in the crystals in a more favourable position to resist deformation, thus resulting in what is known as strain-hardening.

To turn to the practical aspect of the subject, it is found that of the more recent metallic materials of possible use in telecommunications there are comparatively few which rely on hot or cold working operations for development of their mechanical properties, but certain copper-base alloys containing silicon and manganese, or nickel, aluminium and silicon possess good mechanical properties coupled with excellent resistance to corrosion.

The Development of Mechanical Properties by Heat-treatment.

By far the greatest number of non-ferrous alloys introduced during the last few years owe their good mechanical properties to the development of age-hardening by heat-treatment. The mechanism of age-hardening was discussed in the section which dealt with heat-treatment. It remains here to draw attention to the remarkable mechanical properties obtainable with certain age-hardening alloys of possible use in telecommunications. Most of these alloys are based on copper, and, broadly speaking, they can be divided into the following groups :

1. Beryllium-copper.
2. Chromium-copper.
3. Heat-treatable nickel silvers and brasses.

All the age-hardening copper-base alloys are noted for their excellent mechanical properties, and some combine good mechanical properties with high electrical conductivity. For this reason certain of the materials have found many uses in the electrical industry, such as for welding electrodes, electrical machinery castings and springs.

One of the advantages of an alloy which is age-hardenable is that, provided the hardening is appreciable, the strength of the casting can be made to approach or even surpass that of material in the cold worked state. Thus, casting as a cheap and easy means of producing a desired shape can be utilised, and, at the same time, mechanical properties of the order associated with an article which has been made by hot or cold working processes are obtained. Where an age-hardening alloy is wrought to shape, the working is nearly always done after the alloy has been quenched from a high temperature, i.e. when it is in the softest possible condition. Reheating for age-hardening then follows. With some alloys the intermediate cold working enables even better mechanical properties to be obtained than those developed by age-hardening alone.

Beryllium-copper Alloys.

The beryllium-copper alloys and their modifications have possibly the greatest commercial application of all the age-hardening copper alloys; they certainly are the most outstanding as regards their mechanical properties. At the same time these alloys are very expensive, owing to the high cost of beryllium, and are, therefore, used only where exceptional mechanical properties are absolutely necessary. Great efforts have been made to make them a more reasonable commercial proposition, and with the recent fall in the price of beryllium, combined with the development of alloys based on the beryllium-copper system, but in which some of the beryllium is replaced by other metals such as cobalt, chromium or nickel, it is likely that these alloys will find greater application.

Straight beryllium-copper usually contains about 2·15 per cent. beryllium. Some figures are given in Table 3 for the mechanical properties of strips of such an alloy in the fully hardened state together, for comparison, with those of cold rolled copper and cold rolled nickel silver (extra hard temper) containing 18 per cent. nickel, 27 per cent. zinc and 55 per cent. copper.

TABLE 3.

Property	Copper	Beryllium-copper quenched from 800°C. and reheated to 300°C. for 2 hours	Nickel silver, extra hard temper
Ult. tensile stress (tons/in^2)	28	78	47
Elastic limit (tons/in.^{2}) ..	10	53	22
Young's Modulus (lb./in.$^2 \times 10^{-6}$)	18·5	18·9	20·2
Elong. % on 2 in.	5·0	6·0	1·5
Vickers hardness	120	380	240
Fatigue strength ($\pm$ tons/in^2) ..	7-9	13-16	9-10

The constituent responsible for the age-hardening of beryllium-copper alloys is a solid solution termed γ. This has a crystal structure of the body-centred cubic type, that of the solvent being of the face-centred cubic form.

As was stated above, the addition of cobalt, chromium or nickel to beryllium-copper enables the beryllium content to be reduced, thus lowering the cost of the alloy; but besides this there is also achieved a refinement of crystal size, and in some alloys a very considerable improvement in electrical conductivity. The two most outstanding alloys in this class were developed in the U.S.A. One contains 97 per cent. copper, 2·6 per cent. cobalt and 0·4 per cent. beryllium; the other consists of 99·5 per cent. copper, 0·4 per cent. chromium and 0·1 per cent. beryllium.

Straight beryllium-copper has an electrical conductivity of 25 per cent. that of copper, but the corresponding figures for the cobalt and chromium-containing alloys are 45 per cent. and 75 per cent. respectively.

Chromium-copper Alloys.

These alloys, like the beryllium-cobalt-copper and beryllium-chromium-copper alloys are finding particular application as electrical castings and welding electrodes in place of copper. They contain 0·5-1 per cent. chromium with about 0·1 per cent. of silicon to act as a deoxidiser. Some figures for the mechanical properties of cast and age-hardened chromium-copper are given in Table 4, together with comparative figures for pure copper.

TABLE 4.

Property	Chromium-copper Cast and age-hardened	Copper Cast
Ult. tensile stress (tons/in.^{2})	20-23	10
Elong. %	20	30-50
Vickers hardness ..	110-130	45

The electrical conductivities of cast chromium-copper and copper are 80 per cent. to 85 per cent. and 80 per cent. to 90 per cent. that of the international standard respectively.

Chromium-copper is also manufactured in the form of wire. The drawing of the wire is carried out either after the wire rods have been heated to 950° C. and quenched, or after reheating for age-hardening at about 500°C. With the latter method the greatest tensile strength is obtained. Some results for mechanical properties are given in Table 5 and are illustrative of the effect of processing.

TABLE 5.

Property	Quenched from 1,000°C., drawn from 0·5 in. to 0·2 in. diam. and reheated at 500°C. for three hours	Quenched from 1,000°C., reheated at 500°C. for three hours and drawn from 0·5 in. to 0·2 in. diam.
Ult. tensile stress (tons/in^2) ..	34	41
Elongation % on 2 in.	15	3·5
Vickers hardness	140	180

It should be noted that it is possible to obtain mechanical and electrical properties from chromium-copper alloys in the form of wire comparable with those of cadmium-copper, a material which up to the present has been considered the most satisfactory high strength copper alloy in place of bronze for subscribers' lines. With the further development of the chromium-copper alloys it seems likely that they may be suitable as an alternative to cadmium-copper for this purpose.

Other Age-hardening Alloys.

The heat-treatable nickel silvers and brasses contain the intermetallic compound nickel aluminide (NiAl), which is more soluble at raised temperatures than at room temperatures in the primary solid solution of the elements present in the alloy. This, of course, gives rise to the development of age-hardening on suitable heat-treatment. These alloys have good elastic properties and are therefore used, among other applications, for springs. In Table 6 are recorded the mechanical properties of some of the heat-treatable nickel silvers and brasses. Water quenching was done from 800° C. and the reheating temperature was 500°C. A comparison of the figures in this table should be made with those given for nickel silver in Table 3.

TABLE 6.

Property	Alloy and heat-treatment			
	Heat-treatable nickel silver		Heat-treatable brass	
	Water-quenched and reheated	Water-quenched, cold rolled and reheated	Water-quenched and reheated	Water-quenched, cold rolled and reheated
Ult. tensile stress (tons/in.^{2})	37	56	37	47
Elastic limit (tons/in.^{2})	18·0	29·0	17·0	25·0
Elongation % on 2 in.	33	6	29·0	11·0
Vickers hardness ..	170	250	155	210

A point of particular interest in most copper-base age-hardening alloys is that besides exhibiting greater mechanical strength than copper-base alloys not susceptible to age-hardening, they have a greater percentage elongation at fracture. This is of great advantage in that it means that fully age-hardened alloys are less brittle than those fully work-hardened.

In conclusion, as was pointed out in the second article of this series, the crystal structure of metals is not so completely understood as that of the non-metals. For this reason the metallurgist in searching for new alloys to meet the ever more exacting demands of the engineer still has to work to some extent by " hit and miss " methods. These methods, however, are gradually being replaced by a more scientific approach to the subject as knowledge of the crystal structure of metals increases, so that ultimately the metallurgist should be in as favourable a position as the chemist in being able to build his materials to order.

Book Review

" THE AMATEUR RADIO HANDBOOK." Second Edition. 328 pp. The Incorporated Radio Society of Great Britain. 3s. 6d.

After a first edition of 5,000 copies, a second printing of 3,000 copies of this handbook made in August, 1939, was reduced so quickly that it became necessary to produce a second edition in the middle of this year ; this is a sure indication of popularity.

The handbook is written in a style calculated to appeal to the amateur with its brighter moments for others. A typical example occurs in discussing ultra-short-wave transmitters where the sidebands are cut up and there is even a risk of the carrier splitting. Further it is implied that unless experiments are particularly directed at high quality audio frequencies greater than 1 kc/s need not be transmited (p.22). This is a very pleasant thought for the telephone engineer who has evidently been experimenting with high quality for some years, maybe without knowing it. An intriguing advantage (!) of duplex working is given on p. 128, where it is stated that either operator may talk at any moment instead of waiting for the other to stop speaking. As an example of manners, maybe bad, but nevertheless it makes its point simply and effectively.

A chapter on crystal band-pass filters is included for the first time, and although mainly dealing with a special type, which one of the chief collaborators has assisted in developing, is obviously a valuable contribution in dealing with interference within crowded frequency bands. The discussion, complete with a short bibliography on frequency measurement, should go far in helping the amateur to minimise interference—however infrequently—from his own equipment outside the amateur bands when amateur transmissions are again permitted after the war. Another useful new feature is the inclusion of a chapter on Workshop Practice.

The formula quoted on p. 234 for the so-called horizon distance should surely read $1{\cdot}23\sqrt{H}$ instead of $1{\cdot}42\sqrt{H}$, where H is the " height " of the observer's eyes in feet. Presumably the writer intended to qualify 1·42 by saying that it made due allowance for the bending of rays round the curvature of the earth, but no such statement is made. The various remarks on the range of ultra-short waves and the credit claimed for the stabilised transmitters and superheterodyne receivers make one doubt if the writer had any appreciable idea of the extent to which the Post Office has extended such radio links into the telephone network of the country. One of the earliest U.S.W. links to come into commercial operation anywhere was that between Guernsey and this country, being opened for commercial traffic early in 1936, after two years' experimental trial. As a matter of interest the propogation path is 85 miles, approximately 1·73 × the horizon distance.

In a work of this kind there must obviously be many points—the reviewer has only indicated one or two such points—with which the radio engineer as distinct from the amateur will disagree, but this in no way detracts from its general utility. Its continued popularity seems assured. A. H. M.

Notes and Comments

Roll of Honour

It is with deep regret that the Board of Editors has learnt of the death of the following members of the Engineering Department while serving with the Armed Forces :—

Belfast Telephone Area : Cully, F., Unestablished Skilled Workman, Lance-Corporal, Royal Corps of Signals.

Birmingham Telephone Area : Rutter, J. L. Unestablished Skilled Workman, Aircraftman, Class II, Royal Air Force.

Bristol Telephone Area : Kemp, W. L., Unestablished Skilled Workman, Petty Officer, Royal Navy.

The Board is glad to be able to record that the following officer, whose name appeared in the Roll of Honour published in the October issue of this Journal, is still alive :—

London Telecommunications Region : Bignell, W. P., Labourer, Private, Duke of Cornwall's Light Infantry.

Lord Tryon

We regret to have to record the recent death of Lord Tryon, who was 69 years of age.

Lord Tryon, as Major C. C. Tryon, had represented Brighton as its Member of Parliament since 1910, and had held ministerial rank since 1919. Lord Tryon's association with the Post Office commenced in 1935, when he became Postmaster-General, a post which he held until his resignation in April, 1940.

Erratum

The author of an article, " A Resistance Compensated Band-Stop Filter," which appeared in the July issue, has drawn attention to a misprint which occurred near the top of the left-hand column on page 84. The expression :

$$\omega_{1\infty}^2 \ \omega_{2\infty}^2 = \omega_2^2$$

should read :

$$\omega_{1\infty}^2 \ \omega_{2\infty}^2 = \omega_1^2 \ \omega_2^2$$

Regional Notes

South-Western Region

RECONSTRUCTION OF BRIDGE

A scheme had been prepared to replace an existing stone arch bridge by a wider and higher structure, but owing to war conditions this was postponed and a sectional steel bridge erected as a temporary measure. Owing to the type of the new structure it was anticipated that considerable rocking would take place and that special steps would be necessary when diverting the Department's plant.

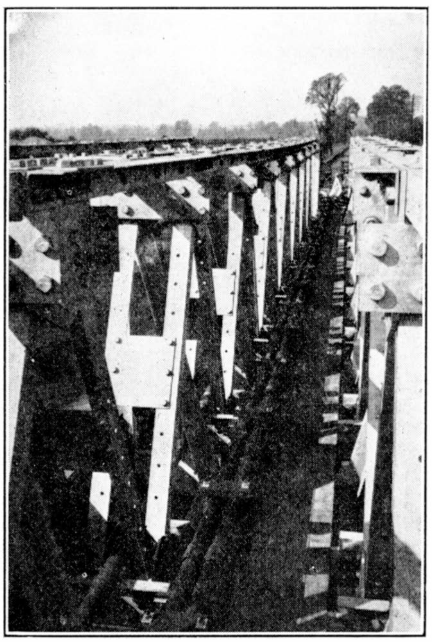


FIG. 1.—VIEW SHOWING DUCT TRACK ACROSS BRIDGE.

The existing Post Office cables were laid in nine steel pipes, but as several heavy gauge cables, which originally served heavy overhead routes, could be replaced by one 200/10 cable, it was found that all requirements could be met by a nest of 6-way ducts.

A meeting was held of representatives of the various public services (gas, water, electricity, Post Office) and the highway authority and the works contractor, and a programme drawn up co-ordinating the various aspects of the work. Minutes of this meeting were issued to all parties concerned.

The bridge runs in an east to west direction. Work commenced with the demolition of the parapet walls and breaking up of the road on the south side, and this side of the steel bridge with its cantilever footway was then erected and traffic diverted to it. The north side was then dealt with in a similar manner and decking for the various services placed in position between the two sides.

When considering possible methods of construction for Post Office plant the following factors had to be borne in mind :—

(a) Facilities were not available for burying pipes or conduit.
(b) The structure would be subject to rocking due to the passage of traffic.
(c) The temporary bridge is to be replaced by a permanent stone bridge later.
(d) The track leading to the bridge was only 3 ft. wide and had to accommodate a 14 in. water main in addition to Post Office plant.

The method adopted to permit necessary movement was to use asbestos cement ducts, and these were arranged in a formation of three layers of two ducts each (Fig. 1), supported on special fittings. These fittings, which were designed and made locally, consist of creosoted elm blocks clamped together with arm bolts and fastened to the decking of the pipeway with coach screws. To allow for expansion and contraction of the bolts, and the swelling and shrinking of the timber, spring washers were fitted and strips of rubber placed between the ducts and the blocks.

The existing ducts were in the carriageway at both ends of the old bridge. The new ducts were laid, from a manhole at each end, sloping up towards the level of the decking and concreted over until clear of the carriageway, from which point they were laid on concrete piers until the bridge structure was reached (Fig. 2).

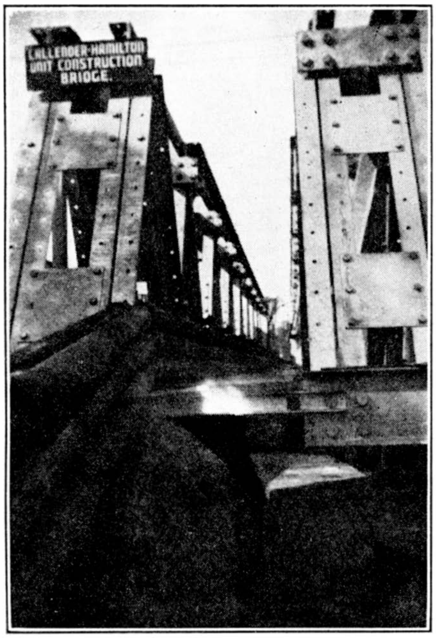


Fig. 2.—Completed Duct Track entering Bridge.

Up to this stage the Post Office plant remained in situ on the old bridge. The new ducts having been completed, the permanent carrier and local cables were drawn in and the circuits changed over. Temporary cable lengths were then drawn in as the first step in changing over the balanced trunk cables, and circuits changed over to them. All the cables in the old ducts were then recovered and the trunk cables drawn into the new ducts, a 4 ft. recess (provided in one manhole for this purpose) being utilised to lengthen the cables as the new route was 2 ft. longer than the old one. Circuits were then changed over to these cables and the temporary cables recovered.

The work of evacuation, reinstatement and reconstruction of the manhole was carried out by the Highway Authority, the duct laying being done by the Department's staff. The whole scheme, which proceeded smoothly and with the minimum interruption to working circuits, is yet another illustration of the value of close co-ordination when several authorities are concerned with different phases of a work.

North-Eastern Region

EXCHANGE TRANSFERS

Despite the additional work and shortage of staff due to the war, three new exchanges have been opened in the Sheffield Area recently. The exchanges concerned are Ecclesfield, where a discriminating satellite exchange with an equipped capacity of 500 multiple replaced a full satellite; Dronfield, where a U.A. No. 14 exchange with an equipped capacity of 600 multiple replaced an obsolescent U.A. No. 9 (By-path) exchange, and Mexborough.

The transfer of Mexborough from C.B.S.1 Multiple to U.A. No. 14 exchange, which was effected on September 12th last, represents a further step in the automatisation of the telephone service of this country. The exchange is housed in the upper floor of the new Post Office building which was opened for business immediately after the outbreak of war. The equipment, which provides for an initial capacity of 500 lines, was installed by Messrs. Siemens Bros. & Co., and comprises 5 A units, 2 B units, 14 C units and 1 D unit. A parallel battery float system with two batteries each of 120 Ah has been installed.

The number of subscribers' circuits transferred totalled 376 and the junctions 47. Mexborough is the centre of an important community of exchanges and has direct routes to 9 exchanges. The auto-manual board is located at Sheffield. Mexborough subscribers have direct access to all the automatic subscribers in the Sheffield ME, Doncaster and Barnsley areas and the equipment installed provides for the same facility when the remaining manual exchanges, to which access to the manual board is now given, are converted to automatic working.

The transfer of the subscribers' lines was expedited by the prior modification of the cord circuits for C.B. working in accordance with Engineering Instruction Auto A 3106.

CABLE FAULTS

An extraordinary number of cable faults, involving eleven different cables, occurred at different points in the York Telephone area within a period of 12 hours on the night of October 31st-November 1st, 1940.

At 18.30 hours an important local cable in Hull was reported faulty, and despite unpleasant weather conditions the localisation and clearing of the fault was immediately put in hand. An hour later the Hull-Leeds No. 2 cable failed, due to a sudden flood of water in a manhole in which a joint was open. The motor pump unfortunately broke down at this critical period; hand pumps were quite inadequate to deal with the inflow and although valuable assistance was rendered by the Fire Brigade while the jointers remained in the manhole holding up the joint until the water reached chest level, it was not possible to prevent the cable core from becoming saturated. Despite the blackout and rain supervising staff from York, 40 miles away, reached the scene, and arrangements had been made for the despatch of replacement lengths within 3 hours.

Meanwhile a further cable fault had isolated Ligglesthorne exchange and before midnight a 200 pair subscribers' cable at Filey had failed. The latter was localised from drawing office records and clearance had commenced by daybreak.

In the early hours of the morning faults developed on the York-Linton and Hull-Hornsea cables, and during the next few hours five further cable faults, of a comparatively minor character, developed.

All the faults were as a direct result of the severe weather and not due in any way to enemy action.

Welsh and Border Counties Region

COAXIAL CABLE ROUTE

A short trunk route consisting of two single coaxial cables one for " go " and the other for " return " and of a length of about 50 miles, most of which is in this Region, has recently been provided. Each cable consists of one coaxial pair, the inner conductor being a solid copper wire 0·104 in. diameter. The outer conductor consists of ten interlocked copper tapes laid together to form a stable flexible tube 0·375 in. internal diameter with a radial thickness 0·030 in. The insulation between the inner and outer conductors consists of a two-ply cotopa string laid round the inner conductor in an open helix, and spiral wrapping of paper which forms a closed cylinder. The insulation between the outer conductor and lead sheath is two wrappings of paper applied tightly over the strips forming the tubular conductor in such a manner to break the joint between the papers. The diameter of the lead sheath is 0·68 in. A short length of subaqueous cable had to be used; this is of a similar type to the land cable, but has an alloy sheath, rubber covered and armoured.

The intermediate repeater stations consist only of one small bay of amplifying apparatus and have been housed in existing telephone exchanges on the route.

Approximately ten miles of 4-way ducts had to be provided over sections of the route, and in one section (2,570 yards approximate) where creepage difficulties had previously been experienced, it was decided to lay asbestos ducts with concrete damping as a precaution against similar trouble in the future. Considerable difficulty was experienced in excavating 23 manholes in one section, owing to the presence of water and running sand, and it was only by making use of " More " trench well point plant that it was possible to carry out the work. In sections of the route where creepage and corrosion trouble had previously been experienced, it was decided to provide antimony lead sheath and protected cable respectively as a precaution against recurrence of the trouble. The two cables were drawn in simultaneously into one duct track.

Where possible drawing-in of the cables was done in approximately 350 yard lengths in order to reduce the number of joints. Coaxial cable jointing is a very highly skilled operation requiring the use of special tools and, therefore, is an expensive operation. Each cable and joint is also protected with flexible metallic tubing in the manholes, the tubing being passed over each cable and extending approximately 6 in. into the duct on either side. The tubing in turn is secured to a flat metal strip which rests on the cable bearers, and thus provides a continuous support for the cables.

Scottish Region

GLASGOW AUTOMATIC CONVERSION SCHEME

Seven new director automatic exchanges have been brought into service since the references to Halfway, Milngavie and Shettleston in previous Notes. In addition an extension of 1,800 lines multiple at Halfway was completed in August, 1940.

The Glasgow auto. exchanges in service are :—

Exchange	Multiple Installed	Date of Opening
Halfway	3,600	20. 9.37
Milngavie	800	15. 8.38
Shettleston	1,200	15. 8.38
Newton Mearns ..	1,000	10.10.38
Barrhead	600	31.10.38
Thornly Park ..	400	14.11.38
Provanmill	500	5.12.38
Possil	400	7. 8.39
Springburn	600	7. 8.39
Busby..	800	4. 9.39

Total Final Selector Multiple = 9,900.

The second stage of the scheme consists of the opening of the joint trunk exchange, which has now been effected, and the simultaneous transfer later of six director exchanges. These exchanges are :—

Central	10,000	lines multiple
City	2,100	,, ,,
Bell	4,200	,, ,,
Douglas	7,800	,, ,,
Paisley	3,500	,, ,,
South	3,300	,, ,,

and are scheduled for opening in the spring of 1941.

The opening of the joint trunk exchange was accomplished in two stages. On Sunday, February 17th, 1940, the demand trunk service was transferred from the H.P.O. to Telephone House. The mechanical trunk equipment was brought into service and 2 V.F. dialling introduced on the routes to Birmingham, Bristol, Leeds, London, Manchester and Newcastle. Routes to other zone centres are still worked on a generator signalling basis. The 2 V.F. dialling scheme is working satisfactorily and the facility whereby calls to subscribers on automatic exchanges at distant zone centres can be completed without the intervention of the distant zone operator is an especially valuable relief in view of the present difficulties.

On Sunday, December 1st, 1940, lending traffic was transferred from central manual exchange to Telephone House, together with traffic from unit automatic exchanges and the manual traffic from the ten advance exchanges scheduled above which was previously handled on a temporary auto-manual suite of 30 positions at Central manual exchange.

Coincidentally the mechanical toll equipment was brought into use. The design of mechanical toll differs from past provincial practice inasmuch as toll exchanges dial the translation of the code of the objective exchange into group selectors acting as tandem 1st code selectors. This arrangement anticipates the future provision of a tandem first code selector of new design.

Transfer schemes in respect of Pollok, Renfrew and Bearsden are to proceed. These exchanges are scheduled to open in December, 1942, but the programme for the remainder of the area has been temporarily abandoned.

Staff Changes

Promotions

Name	Region	Date
From Reg. Engr. to Acting Principal.		
Beer, C. A.	Telecomms. Dept.	—
From Exec. Engr. to Acting Tel. Manager.		
Gifford, H. W.	Cardiff	17.10.4
From Exec. Engr. to Acting Reg. Engr.		
Baines, J.	S.W. Reg.	20.8.40
Morrill, A. E.	S.W. Reg.	1.10.40
From Asst. Engr. to Acting Exec. Engr.		
Lowne, W. R. J.	Mid. Reg.	28.9.40
Thomsett, H. S.	H.C. Reg.	19.10.40
Chapman, F. G.	E.-in-C.O.	31.10.40
Gambier, J. E.	S.W. Reg.	31.10.40
From Chief Insp. to Acting Asst. Engr.		
Pitloh, T. P.	N.E. Reg.	9.10.40
Turtle, G. R.	Mid. Reg.	20.10.40
Drew, L. C.	H.C. Reg.	1.10.40
Dye, F. W. G.	E.-in-C.O.	26.9.40
Twycross, A. E.	Mid. Reg.	26.9.40
Anderson, J.	N.E. Reg.	6.10.40
Davey, F. R.	E.-in-C.O.	25.11.40
Legood, F. J.	E.-in-C.O.	20.11.40
McKie, A. N.	E.-in-C.O.	30.11.40
Stonebanks, A. M.	S.W. Reg.	30.11.40
Stone, M. C.	S.W. Reg.	30.11.40
From Chief Insp. to Chief Insp. with Allowance		
Tansley, R.	N.W. Reg.	1.10.40
From Insp. to Acting Chief Insp.		
Harrison, T. W.	Mid. Reg.	9.8.40
Reardon, J.	E.-in-C.O.	27.10.40
Drew, F. C.	S.W. Reg.	22.9.40
Lush, A.	H.C. Reg.	11.8.40
Yates, G. A.	Mid. Reg.	9.8.40
Weeks, O. J.	H.C. Reg.	10.11.40
Spice, W. H. J.	L.T. Reg.	24.7.40
Cook, A. E.	L.T. Reg.	12.7.40

Name	Region	Date
From Insp. to Acting Chief Insp.—continued		
Butcher, E. E.	H.C. Reg.	1.9.40
Ryan, R. L.	E.-in-C.O.	6.10.40
Emery, E. A.	L.T. Reg.	12.7.40
Todd, D. W.	L.T. Reg.	21.7.40
Facer, J. H.	Mid. Reg.	27.10.40
Houghton, C. W.	S.W. Reg.	10.11.40
Young, G.	Mid. Reg.	14.11.40
Wearn, R. G. O.	Mid. Reg.	9.8.40
Philipson, W.	Scot. Reg.	To be fixed later
May, E. G. A.	H.C. Reg.	10.11.40
Ingram, E.	N. Ire. Reg.	14.10.40
Masters, E. J.	H.C. Reg.	5.9.40
Duggan, W. G.	Scot. Reg.	13.11.40
Surman, W. L.	Mid. Reg.	21.7.40
Newson, F. W.	E.-in-C.O.	30.7.40
Stapley, G. R.	Mid. Reg.	25.8.40
Britton, A. D.	H.C. Reg.	11.8.40
Endecott, A. H.	W. & B.C. Reg.	27.10.40
Tinto, J. M.	S.W. Reg.	23.9.40
Beer, T.	W. & B.C. Reg.	1.7.40
King, W.	H.C. Reg.	To be fixed later
Brunel, L. F. J.	E.-in-C.O.	26.9.40
Hardy, J.	N.E. Reg.	1.11.40
Sinstead, H. A.	L.T. Reg.	4.12.40
Taylor, I.	N.W. Reg.	1.10.40
Smith, J. P.	N.E. Reg.	6.11.40
Fox, W. H.	E.-in-C.O.	7.4.40
Raffles, H.	S.W. Reg.	10.11.40
From Prob. Insp. to Insp.		
Hetherington, T.	E.-in-C.O.	10.8.40
From S.W.1 to Acting Insp.		
Forster, G. C.	E.-in-C.O.	26.4.40
Anderton, C.	E.-in-C.O.	1.7.40
Price, H.	E.-in-C.O.	2.9.39
Osborne, C. A.	E.-in-C.O.	28.10.40
Wilshire, A. V.	E.-in-C.O.	28.10.40
From U.S.W. to Asst. Chem. or Asst. Phys.		
Young, E. J.	Test Section, B'ham	3.9.40

Transfers

Name	Region	Date
Reg. Engr.		
Wallcroft, F. E.	E.-in-C.O. to W. & B.C. Reg.	25.11.40
Asst. Engr.		
Brown, R. C. C.	E.-in-C.O. to S.W. Reg.	21.10.40
Insp.		
Sims, G. H.	L.T. Reg. to E.-in-C.O.	16.9.40
Cheyney, C. E.	L.T. Reg. to E.-in-C.O.	16.9.40
Roberts, H. T.	E.in-C.O. to L.T. Reg.	18.11.40

Retirements

Name	Region	Date
Exec. Engr.		
Baldwin, D. Z.	E.-in-C.O.	20.8.40
Cleaver, J.	S.W. Reg.	30.9.40
Bowyer, G.	S.W. Reg.	31.10.40
Asst. Engr.		
Tanner, G. F.	E.-in-C.O.	30.11.40
Gray, G.	L.T. Reg.	30.11.40
Chief Insp. with Allowance		
Mercer, H.	N.W. Reg.	30.9.40
Chief Insp.		
Hartnell, C. H. B.	E.-in-C.O.	30.9.40
Clifford, F.	L.T. Reg.	3.12.40
Mullis, P. R.	W. & B.C. Reg.	11.10.40
Crosby, S. C.	W. & B.C. Reg.	31.8.40

Deaths

Name	Region	Date	Name	Region	Date
Asst. Engr.			*Insp.*		
Mills, A. D. ..	.. Scot. Reg.	13.10.40	Palmer, R. W. L.	.. E.-in-C.O.	20.11.40
Chief Insp.					
Patrick, F. H.	.. L.T. Reg.	19.9.40			

CLERICAL GRADES

Promotions

Name	Region	Date	Name	Region	Date
From E.O. to S.O.			Wolstenholme, --	.. Provinces	19.10.40
Smith, G. S. ..	.. E.-in-C.O.	11.9.40	Gallagher, F...	.. Provinces	7.11.40
Knightbridge, H. T...	E.-in-C.O.	3.11.40			
From C.O. to E.O.			*From C.O. to H.C.O.*		
Martin, H. J...	.. E.-in-C.O.	4.10.40	Clarke, M. A...	.. Provinces	3.11.40
Park, W. H. ..	.. E.-in-C.O.	11.10.40	Dickinson, F. E.	.. Provinces	27.10.40
Botelle, S. A...	.. E.-in-C.O.	11.11.40	Mogford, V. H.	.. Provinces	3.11.40
Bray, S. F. ..	.. E.-in-C.O.	11.11.40	Guyatt, L. G. J. O. ..	Provinces	2.12.40
Craik, A. ..	.. E.-in-C.O.	28.11.40	Brown, A. E...	.. Provinces	1.10.40
Adams, W. H.	.. E.-in-C.O.	28.11.40	Brook, H. ..	.. Provinces ..	.. To be fixed later

Retirements

Name	Region	Date	Name	Region	Date
S.O.			*C.O.*		
Laws, W. ..	.. E.-in-C.O.	2.11.40	Wright, E. K. (Miss)	E.-in-C.O.	9.11.40

DRAUGHTSMAN GRADES

Promotions

Name	Region	Date	Name	Region	Date
D'man Cl. I to Acting Senr. D'man.			*D'man Cl. I to Acting Senr. D'man.*		
Tait, W. D. ..	.. Scot. Reg.	30.8.40	Lennon, F. T.	.. H.C. Reg.	24.11.40
Mountain, A. J. A. ..	S.W. Reg.	6.10.40			

The Board of Editors is not responsible for the statements made or the opinions expressed in any of the articles in this Journal, unless such statement is made specifically by the Board.

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