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By

L. E. RYALL, Ph.D. Eng. (Lond.), A.M.I.E.E.

Read before the London Centre of the Institution on the 8th May, 1934

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Introduction.

This paper describes some new forms of apparatus, many of them involving novel circuits that have been developed recently in connection with work relating to telephone repeater transmission systems. The scope of the paper falls into two parts. The first part deals with testing apparatus and includes various forms of oscillators and direct-reading attenuation measuring sets. The second part deals with developments associated with the speech-signal transmission circuit, such as means for reducing valve distortion in amplifiers, and a new method for obtaining a voice-operated switch, together with its application to echo-suppressors. Further improvements have enabled the satisfactory operation of a 2-way voice-operated switching system to be obtained, in which the principle is applied to a stabilised 2-wire repeater circuit or to a loud-speaker telephone. A description of the loud-speaker telephone which has been developed for general use by subscribers, having particular reference to the switching operations, is given.

Part I.—Transmission Measuring Sets.

A transmission measuring set consists essentially of a signal generator and a signal level or voltage indicator. To measure the attenuation of a circuit, a signal of known strength—usually 1mW—is applied to the circuit and the level of the signal received at the other end is measured. The ratio of this measured signal to the transmitted signal gives the attenuation of the circuit. An attenuation-frequency characteristic is obtained by repeating the test over the range of frequencies required. The process that has hitherto been employed at repeater stations is as follows :—

(i) Setting the oscillator to give the desired signal frequency.

To do this the settings of six dials or switches have to be read from a calibration chart, and the corresponding adjustments of the dials made. Errors in reading the chart or setting the dials can easily be made as five of the calibration figures bear no relation to the value of the signal frequency.

(ii) Adjusting the output level of the oscillator to line to be 1 mW.

A comparison method against a calibrated direct current using a thermo-couple is employed. Unfortunately, there is a considerable time lag in the operation of the thermo-couple so that either the operation is low, or else errors arise due to incorrect estimations of the final galvanometer reading from the deflection prior to its coming to rest.

(iii) Measuring the received signal level.

Again a comparison method is used.

This involves setting up a local oscillator to give 1 mW into an artificial attenuator as described above and adjusting the signal level until the level of the " received " and " local " signals as indicated by an amplifier-rectifier instrument are equal. The line attenuation is then equal to the loss indicated on the attenuator.

All these adjustments require to be made at each frequency setting, and as the signal frequency is varied in steps, no indication of the transmission characteristic between those steps is obtained. This often entails a considerable loss of time where measurements near the " cut off " frequency are being made.

Direct Reading Transmission Measuring Apparatus.

Direct reading transmission measuring apparatus has now been developed which very considerably simplifies the operation and reduces the measuring time. Before describing the apparatus in detail the method of operation will be set out :—

(i) Setting the oscillator to give the desired signal frequency.

A dial is rotated until the indicator is opposite the frequency required. A logarithmic scale of frequency is provided.

(ii) Adjusting the output level of the oscillator to line to be 1 mW.

The output of the oscillator at any one frequency is adjusted to be 1 mW as recorded on the associated direct-reading attenuation measuring set. Since the measuring set records levels directly in terms of decibels above or below 1 mW, and there is practically no operating time lag, this adjustment is quite speedy. The output level of the oscillator remains absolutely constant over the frequency range.

(iii) Measuring the received signal level.

The received signal gives a direct visual indication of its level on the measuring set.

(iv) To make a frequency-attenuation test of a circuit.

The operator at the transmitting end transmits 1 mW to line and varies the signal frequency over the required frequency range by rotating the oscillator calibration dial, whilst the observer at the receiving end of the circuit observes, and if necessary, logs the attenuation values at any desired frequencies.

It is possible to make this operation entirely automatic, and the visual indication of the attenuation over the frequency range is then recorded on a chart, but it is doubtful if such automatic recording offers advantages over the method described, as operators are required at both the transmitting and receiving ends to set up the apparatus, and whilst they are doing this they could make the frequency-attenuation test.

The design of the oscillator and the transmission measuring set which make this simplified method of measuring possible will now be described :—

A Precision Heterodyne Oscillator.

The heterodyne oscillator is probably the best known form of oscillator in which the frequency is continuously variable and in which a direct scale of frequency is employed. The principle of the heterodyne oscillator was originated in the Post Office Engineering Department Research Section some years ago and a number of designs have been developed, which, whilst having certain advantages over the low-frequency tuned circuit straight oscillator, have suffered from disadvantages which have prevented them from being adopted for repeater station use. The requirements of a good oscillator, the reasons why these requirements are difficult to meet with a heterodyne type of oscillator, and how these difficulties have been overcome in the present design will now be given.

The main requirements of a heterodyne oscillator are :—

1. Accuracy of frequency calibration.
2. Frequency stability.
3. Purity of wave form.
4. Constancy of output voltage over the frequency range.

Any form of heterodyne oscillator, such as shown diagrammatically in Fig. **1**, consists of two high-frequency oscillators, having a fixed frequency F_1 and a variable frequency F_2, respectively. The frequency F_2 is changed by means of a variable air condenser calibrated direct in beat frequency. $F_1 - F_2$. The two high frequency signals are rectified and a signal of frequency $F_1 - F_2$ is produced, which after suitable amplification passes to the output. If a pure beat note signal is required, one at least of the high-frequency signals must be free from harmonic, and a band-pass filter (B.P.F.) should precede the signal rectifier. A low-pass filter (L.P.F.) should also follow the rectifier to prevent signals of the frequencies F_1 and F_2 from passing to the output.

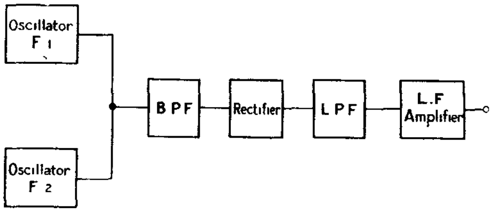


Fig. 1.—Heterodyne Oscillator (Diagrammatic).

The complete circuit diagram of the oscillator developed for repeater station use is shown in Fig. **2**. Its main characteristics may be summarised as follows :—

Scale—Logarithmic 0.2% accuracy. ± 1 cycle per second.
Stability from immediately upon switching on ± 1 cycle per second per day completely unaffected by temperature changes.
Harmonic Content less than 0.3%.
Constant Output Voltage throughout range to less than ± 0.1 db. and reasonably independent of supply voltage fluctuations.
Output Impedance of 600 ohms very nearly non-reactive and output balanced with regard to earth potential for repeater station work.
Pure Output up to 0.2 watts with 130 V.H.T. supply, or 4 watts with 400 V.H.T. supply.
Mains or Battery operated.

Factors Influencing the Accuracy of the Frequency Calibration.

The main disadvantage of heterodyne oscillators

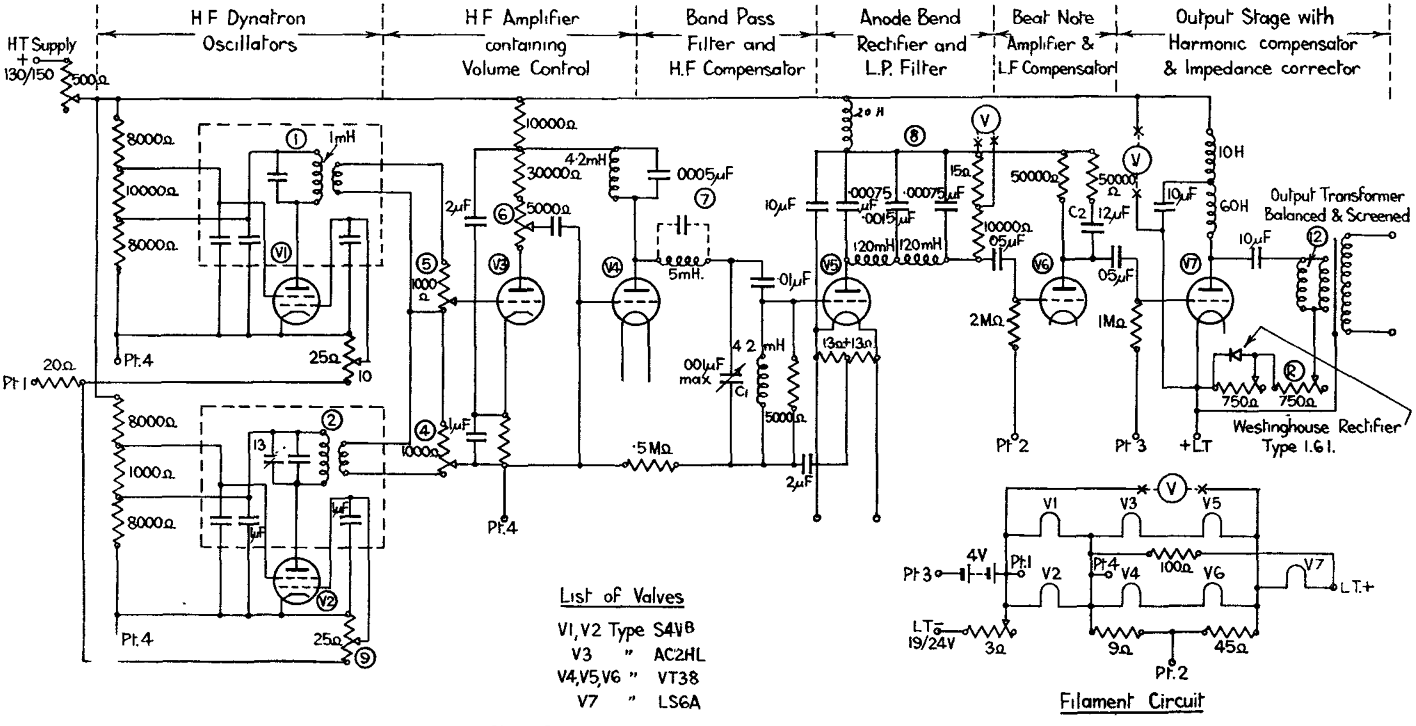


Fig. 2.—Precision Heterodyne Oscillator.

in the past has been their frequency instability, and so the following rather detailed remarks regarding stability are given.

The calibration may be rendered unreliable by :—

(*a*) A change in " zero beat " frequency due to unequal frequency changes of the two H.F. oscillators.

(*b*) A change in the frequency calibration of the condenser controlling the variable-frequency oscillator due to the fundamental frequency of the two oscillators altering.

(*c*) A change in the capacity calibration of the variable condenser.

The error (*a*) may be due to a number of causes, of which temperature variations and the type of oscillating circuit used are probably the most important. Temperature changes affect both the tuning-condenser capacity and the tuning inductance. By using the best sub-standard mica condensers with a very low temperature coefficient the condenser error is reduced to a minimum. The effect of temperature on the inductance coils is liable to cause instability in the value of the inductance unless the former on which the coil is wound has the same linear coefficient of expansion as the copper wire of the coil. Further, compensation is required to ensure that the inductance has practically no temperature coefficient, as it is not possible to obtain simple uncompensated inductance coils sufficiently matched with regard to temperature coefficient. The screening boxes around the coils will also be affected by temperature changes, and they must be of such a size that the resultant effect on the inductance coils of the temperature changes of the boxes is negligible. Mechanical instability of the coils and screening boxes must be avoided.

The type of oscillatory generator employed should be such that the generated frequency is unaffected by variations of the valve characteristics. The dynatron oscillator is the most satisfactory form of generator as the oscillation is produced by connecting a simple parallel resonant circuit in the anode circuit of a 4-electrode screened grid valve, and adjusting the respective grid and anode potentials so that the anode-kathode resistance is negative. Since the anode-kathode capacity is extremely small, the effect of changes of this capacity due to any expansion of the electrode system of the valve is negligible. Also, there is no variable coupling factor as is found in the usual form of triode oscillators using anode and grid coupling coils.

The error (*b*) will only be serious if the changes in the generated frequencies, although equal, are large.

The error (*c*) is equal to one half the error that may occur due to instability in the capacity calibration of the variable condenser.

The Values of the High Frequencies F_1 and F_2.

The selection of these frequencies to give a beat-frequency range up to 12 kilo-cycles/sec. is largely determined by the magnitude of the capacities necessary in the associated oscillatory circuits. Using 1,000 micro-henry inductance coils the tuning capacity is approximately 2,660 micro-micro-farads at 100 kilo-cycles/sec., increasing to 3,430 micro-micro-farads at 88 kilo-cycles/sec. This increase of 770 micro-micro-farads is obtained with the variable air condenser controlling the beat-frequency. Any reduction in these frequencies will necessitate larger tuning inductances and a considerably larger incremental capacity of the variable air condenser. This is difficult to obtain if the condenser calibration is to have an open frequency scale. On the other hand, increases in the heterodyne frequencies are also undesirable as a greater degree of accuracy is required in maintaining these frequencies to give the same accuracy of beat-frequency.

Type of Components used in the Oscillatory Circuits.

Since a variation of capacity of 1 micro-micro-farad, or a variation of inductance of 1 micro-henry, changes the beat-frequency by about 20 cycles/sec. and 50 cycles/sec. respectively, these components must be of a high standard of accuracy. The fixed tuning capacities are sub-standard grade mica condensers and the variable air condenser is a Sullivan laboratory-first-grade air condenser with specially shaped plates giving a logarithmic law of beat-frequency, from 50 to 12,000 cycles/sec. The scale shape in terms of beat-frequency is shown in Fig. **3**. An additional air condenser with a capacity variation of 5 micro-micro-farads is also used to obtain zero beat frequency, when the calibrated condenser is set to give zero frequency. The calibration accuracy of the condenser is between 0.1 and 0.2 per cent., and provided it is mounted with the spindle vertical it should retain this accuracy for long periods. The reading accuracy is at least 0.2 per cent. over the whole range.

The inductances used are 1,000 micro-henry Sullivan-Griffiths temperature-compensated standard-inductance coils which have temperature coefficients of less than 6 parts in 1,000,000 per degree centigrade. They are mounted in copper screening boxes, 10 ins. × 10 ins. × 7 ins. A pick-up coil consisting of 4 turns is mounted about $2\frac{1}{2}$ inches from the end of the main coil. The mutual inductance between the two coils is approximately 3 micro-henries.

The Method of Controlling the Oscillating Valves.

The valves used are Mullard screened grid, indirectly-heated, type S4VB. They are mounted just outside the coil screening boxes. The anode and screened grid voltages are obtained from potentiometer-resistances connected across the H.T. supply. The voltages are 36 and 79 approximately when the H.T. voltage is 130 and 40 and 87 respectively with an H.T. voltage of 150. Separate potentiometers are used for each valve to prevent coupling between the two oscillators. The control grid-voltage is obtained from variable potentiometers and can be varied between 0 and -1.5 volts with respect to the kathode. By-pass condensers are connected from the potentiometer supply points to the valve kathode. The negative control grid-voltage is increased until it is just below

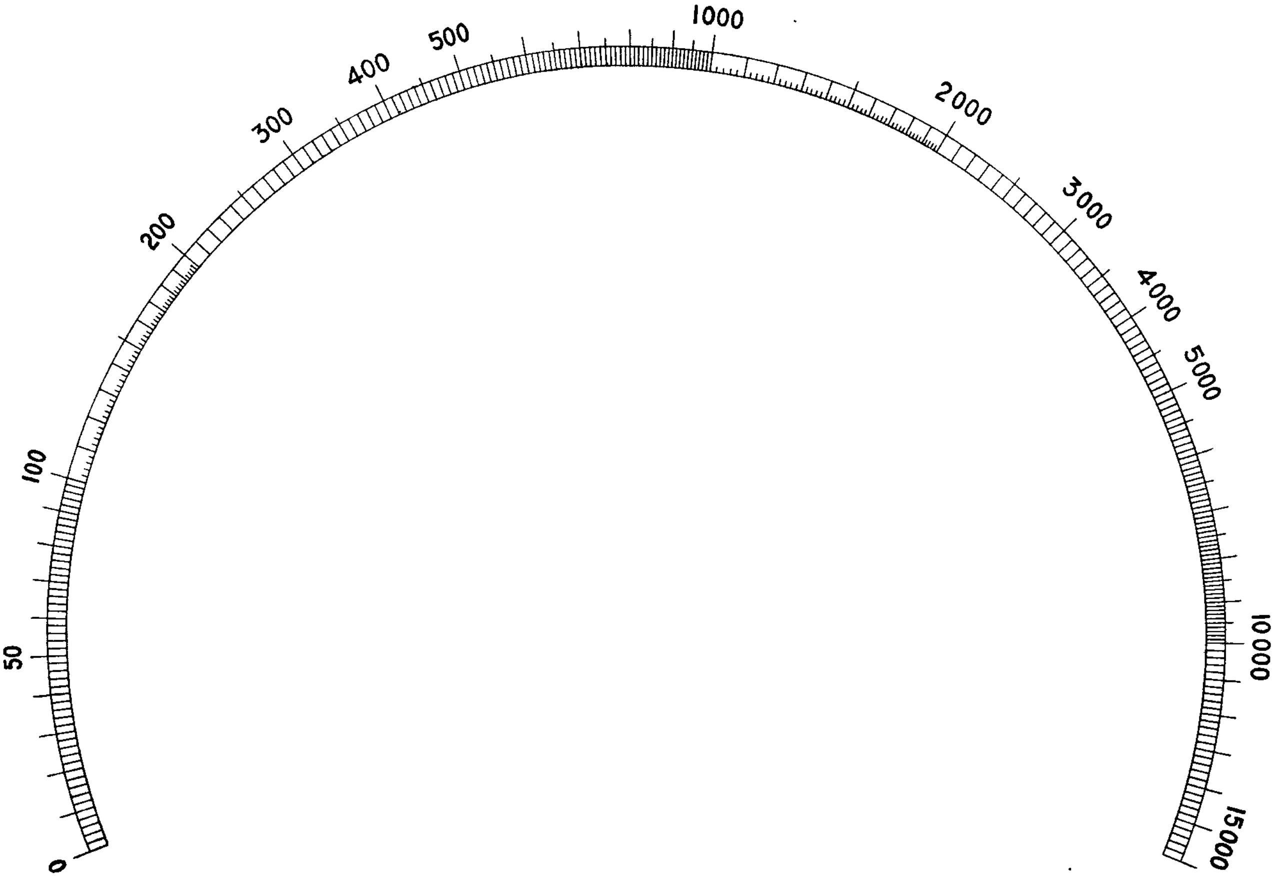


Fig. 3.—Frequency Scale of Ryall- Sullivan Heterodyne Oscillator.

the value required to give maximum oscillation. The variable-frequency oscillator is adjusted when the frequency is 88 kilo-cycles/sec.; *i.e.,* with the beat note condenser pointer at 12,000 cycles/sec. The setting of the control grid-voltage can either be determined by observing the beat-frequency output when the oscillator under test is providing the smaller of the two heterodyne signals or by noting the change in the rectifier anode current when only the oscillator under test applies a signal to the rectifier valve.

The oscillating condition is determined, not by frequency stability, but by output-voltage stability. For a maximum-frequency stability the negative resistance of the valve should be made only slightly less than the dynamic impedance of the oscillatory circuit. The amplitude of the oscillation will then vary considerably with the generated frequency and with supply-voltage changes. To obtain a constant output at all values of the beat-frequency, and also when the supply-voltage changes slightly, is considered of greater importance than the maximum stability, provided that the stability otherwise obtained is in excess of normal requirements.

The effect of 5 per cent. supply-voltage variations is to change the beat-frequency approximately 0.15 cycles/sec. when the common heater and grid-bias battery changes, and less than 0.1 cycles/sec. in the case of the supply to the anode and screened grid.

Substitution of one oscillator valve for another valve of a similar type may cause a change in the beat-frequency. This change can be corrected by re-setting the zero, and no change can then be measured in the frequency calibration.

" Zero beat " of the oscillator is recorded on a milliameter in the anode circuit of the detector valve. The frequency stability is such that the frequency does not vary more than 1 cycle/sec. over long periods of days and the change is less than 0.2 cycle/sec. in a 15 minute period. Furthermore, the beat-frequency that is obtained when oscillations commence after initially switching on the oscillator supplies is within 1 cycle/sec. of the normal value, and hence time is not wasted in waiting for the oscillations to " settle down before using the instrument.

Purity of Output.

Sources of possible distortion and their correction.

(*a*) " Pull-in " of the two heterodyne oscillators will occur at low frequencies due to coupling, either directly or *via* the pick-up coils, To minimise this the oscillator circuits and their associated voltage supplies are kept separate and the pick-up coils have only a small mutual inductance with the main oscillator coils. Also, there is no direct coupling between the two pick-up coils which are connected across separate 1,000 ohm potentiometers. The variable potentiometer tappings are connected in series in the grid-circuit of an amplifying valve. The potentiometer connected to the variable-frequency oscillator coil supplies the main high-frequency signal, and the potentiometer connected to the fixed-frequency oscillator coil supplies the heterodyning signal, and this potentiometer controls the beat-frequency output. " Pull-in " between the two oscillators does not occur until the beat-frequency between them is less than 0.2 cycles/sec. Fig. **4** shows the oscillator wave form at 2 cycles/sec., and it appears sinusoidal.

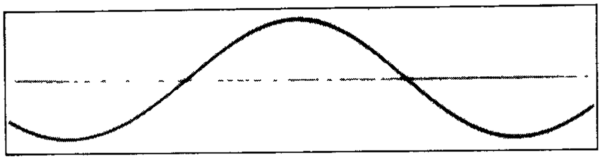


FIG. **4**.—OSCILLATOR WAVE FORM—2 C.P.S.

(*b*) An impure wave form of the high-frequency signal when rectified will cause harmonics of the beat-frequency to be produced. After two stages of amplification the combined H.F. signals are passed through a single section band-pass filter shown in Fig. **2**. The shunt arms primarily have a resonant frequency of 95 kilo-cycles/sec., but an additional variable condenser is connected across the terminating impedance to provide high-frequency equalisation of the beat-frequency signal The series arm consists of a 5 mH dust-core coil designed to resonate, by virtue of its self-capacity, at approximately 200 kilo-cycles/sec. The introduction of a 0.01 micro-farad coupling condenser enables the terminating impedance to be connected directly in the grid-circuit of the detector valve,and at the same time eliminates any low-frequency signals which may have been present in the H.F. amplifier, from the beat-frequency signal. The series-resonance frequency of this condenser and the 5 mH coil must be above the highest beat-frequency signal. If this resonance occurs in the beat-frequency range it will affect the output voltage at this frequency and may cause self-oscillation of the combined high and low-frequency amplifiers. A low-pass filter section in which the shunt arms are replaced by simple condensers satisfactorily eliminates the harmonics of the heterodyning frequencies, but the transmission loss is not uniform over the variable-frequency range of 100 to 88 kilo-cycle/sec., and it is difficult to obtain a uniform beat-frequency output at all frequencies.

(*c*) Distortion also occurs in the rectifier. Anode-bend rectification is used with a steady grid-bias voltage of 8.5 volts applied to the rectifier valve (P.O. type V.T.38). The magnitude of the H.F. signal voltage (before heterodyning) that is applied to the grid is readily deduced from the increase of anode-current that it produces in the detector valve. Using valves of the same type the applied signal voltage does not vary more than 10 per cent. when the corresponding equal increases in anode-current are obtained. An increase of anode-current of 0.35 mA, which corresponds to 3 volts applied to the grid is a very satisfactory working condition. Grid-leak rectification was also tried, but under the best conditions the harmonic produced for a given output is approximately 10 db. above that obtained with anode-bend rectification. The low-frequency amplifier following the rectifier is such that 100 mW output is obtained with about 0.75 volts of the fixed-frequency signal imposed on a variable-frequency signal of 3.0 volts in the grid-circuit of the rectifier valve. This low ratio between the two signals minimises the distortion present in the rectifier valve.

(*d*) Additional distortion will occur in the L.F. first-stage amplifying valve, but by using an anode feed resistance of 50,000 ohms (equal to 10 times the normal valve impedance) and by reducing the grid-bias voltage to a minimum, consistent with the absence of grid-current at full output, this distortion is kept very small.

(*e*) The output stage can also produce considerable distortion. The valve distortion is kept small by using an LS6A type of valve which is capable of handling large powers. The output transformer is choke-capacity-coupled to the output valve so that no direct current passes through the output-transformer windings. The choke in the anode-circuit has a resistance of 500 ohms and the inductance varies from 65 henries with 10 mA (DC) flowing to 75 henries with 60 mA (DC) flowing through the winding. The output transformer has a mumetal core. The inductance of the output (600 ohm) winding is about 15 henries and the leakage inductance is about 3.7 millihenries. The importance of this low-leakage inductance is discussed later. The effect of the transformer distortion is not serious until the frequency falls below 50 cycles/sec.

It was initially considered that a push-pull output stage would reduce the harmonic present and this was installed. An additional output valve is required and in addition a " para-phase " stage incorporating another amplifying valve, so that the signal-voltage could be applied to the grids of both of the output valves in correct phase relationship. The introduction of a transformer to do this would mean additional distortion and a non-uniform frequency response. The push-pull stage only reduces the harmonic content of the output stage, but leaves the harmonic produced by the detector valve and the other L.F. amplifying valves. This residual distortion was found to be greater than that of the output stage, especially for small output voltages.

(*f*) *Correction of harmonic distortion.*

A novel device for reducing the amount of harmonic present has been introduced into the output stage of the oscillator. This consists of a metal oxide rectifier in parallel with a resistance, and the combination is connected in series with the output circuit. This rectifier combination produces harmonic distortion in the same manner as a thermionic valve, and by suitably choosing the type of rectifier and the value of the shunting resistance the valve distortion of the oscillator can be compensated and reduced by at least 10 decibels. (Further details of this form of distortion compensator for use with valve amplifiers are given later.) At small outputs practically no harmonic of any kind remains, especially for fundamental frequencies of 300 cycles/sec. and above. Fig. **5** shows the relation between the harmonic content and the signal voltage for different outputs over the frequency range of the oscillator.

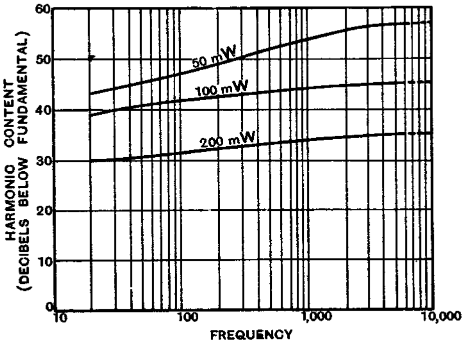


Fig. **5**.—Harmonic Content of Oscillator with 130v. H.T.

(*g*) *Distortion due to H.F. interference signals.*

Unless the H.F. amplifier is adequately screened, including the connections to the oscillator " pick-up " coils, H.F. signals of frequencies within the range of the carrier frequencies may be superimposed on the oscillator signals due to " pick-up " from radio stations. Furthermore, when large outputs are produced of a relatively high-frequency beat signal the harmonics present may themselves be introduced into the H.F. amplifier and cause additional heterodyne signals, unless the H.F. amplifier is screened from the L.F. amplifier.

(*h*) *Distortion due to L.F. interference signals.*

The band-pass filter is connected to the grid of the detector valve in the manner shown so that there is a high L.F. impedance between this grid and the H.T. supply of the prior H.F. amplifier and a very low L.F. impedance between the grid and the filament centre point of the detector valve. This arrangement is found to cut out practically all battery interference.

Uniformity of Output Voltage over the Frequency Range.

(*a*) *Sources of variation, their prevention and correction.*

A variation of the output voltage of the H.F. oscillator will occur when the frequency changes from 100 to 88 kilo-cycles/sec, to give a beat-frequency of 0 to 12 kilo-cycles/sec, due to a change in the dynamic impedance of the resonated coil in the anode circuit of the oscillator valve. This change is kept small by selecting the electrode potentials of the valve so that the negative anode-kathode impedance is much less than the dynamic impedance of the resonated coil. It is preferable that the maximum dynamic impedance should occur at a frequency greater than 100 kilo-cycles/sec. so that the output voltage of the oscillator tends to decrease as the frequency falls from 100 to 88 kilo-cycles/sec., as this form of output-frequency characteristic readily lends itself to amplitude compensation in the band-pass filter.

(*b*) *Band-pass filter transmission losses.*

The transmission loss of the H.F. band-pass filter can be controlled by varying the capacity C_1 in shunt with the terminating impedance (see Fig. **2**). Thus by increasing this capacity above the normal value the transmission loss is decreased at 88 kilo-cycles/sec. as compared with the loss at 100 kilo-cycles/sec. This results in a rising voltage/beat-frequency characteristic of such a form that it can be adjusted to compensate the loss caused by capacity leakage and leakage inductance in the L.F. amplifier. The change in beat-frequency output voltage due to a change in one of the H.F. signal voltages is reduced to a second-order effect by making the varying signal-voltages the larger of the two heterodyne voltages. Thus relatively large changes in output of the variable-frequency oscillator to give a small change of beat-frequency output are easily controlled, and the adjustment of the capacity C_1 in the band-pass filter is not critical. Fig. **6** shows the beat-frequency output characteristic with the capacity C_1 varied to give different amounts of compensation. When C_1 equals 0.00063 micro-farads the variable-frequency signal voltage applied to the grid of the rectifying valve is constant and the loss of beat-frequency output at high frequencies is due to the losses in the L.F. amplifier.

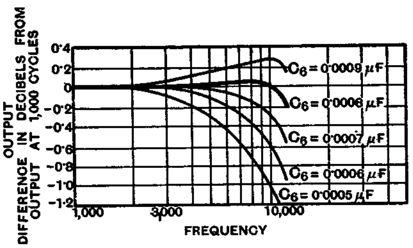


Fig. **6**.—H.F. Corrector Characteristics.

(*c*) *Low-frequency amplifier losses.*

At high-frequencies losses may occur in the low-pass filter as well as in the amplifier and output transformer, but it has been seen above that these losses are less than 0.6 db. at 10,000 cycles/sec. and can be compensated in a very simple manner.

At low-frequencies transmission losses occur due to the impedance of the anode battery-by-pass condenser rising and becoming comparable with the anode circuit impedance. Partly for this reason, and also to keep the large A.C. output voltage from the anode battery as much as possible, the output transformer is capacity coupled to the kathode of the output valve and not to the anode battery. Serious loss in the inter-stage coupling is avoided by using coupling condensers and resistances with a time constant greater than 0.05 secs. Since it may be desirable to obtain the H.T. supply to the oscillator from a " mains unit " it is arranged that the amplification of the L.F. amplifier shall fall off below 20 cycles/sec. so that very low-frequency oscillation shall not occur.

The shunt loss of the output transformer is about 0.25 db. at 40 cycles-sec. The overall low-frequency transmission loss of the oscillator is shown in Fig. 7. Suitable compensation is provided on the interstage L.F. amplifier. The effect of varying the value of the capacity C_2 on the frequency equalisation is also shown. It will be observed that the output does not vary from the value at 800 cycles/sec. by more than 0.1 db. when C_2 is 0.12 microfarads until the frequency falls below 20 cycles/sec. The values of C_1 and C_2 for high and low-frequency compensation are best selected by trial for each oscillator if the optimum constancy of output is required. The change in output voltage over the beat-frequency range for different values of the load impedance is shown in the following table :—

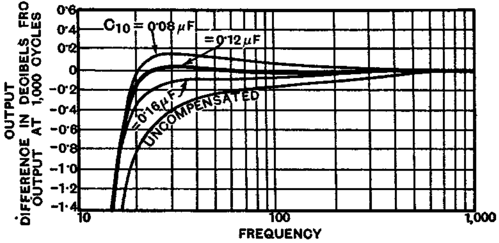


Fig. 7.—L.F. Corrector Characteristics.

TABLE SHOWING THE CONSTANCY OF BEAT-FREQUENCY OUTPUT.

Output = 100 mW at 1,000 cycles/sec.

Frequency cycles/sec.	Output variation from 1,000 cycles/sec. value (db.).		
	300 ohms load.	600 ohms load.	1,000 ohms load.
15	−1.0	−1.4	−1.6
18	−0.2	−0.27	−0.35
20	<±0.05	−0.09	−0.2
30	,,	<±0.05	−0.12
50	,,	,,	−0.08
200	,	,,	−0.08
300 to 3,000	,,	,,	<±0.05
4,000	,,	,,	+0.1
8,000	−0.08	,,	+0.15
9,000	−0.13	,,	+0.1
10,000	−0.18	,,	+0.05
11,000	−0.23	−0.06	<±0.05
12,000	−0.32	−0.2	−0.1

Constancy of Output Impedance.

For repeater station use this impedance should be 600 ohms non-reactive. This value is determined by the output valve impedance. The output-transformer ratio is such that the output impedance with normal valves is approximately 450 ohms, and can be varied by adjusting the resistance R_1 in series with the valve impedance. The output voltage at, say 1,000 cycles/sec., is measured on open circuit (or with a load greater than 50,000 ohms) and then with a load of 600 ohms, the resistance R_1 is adjusted until the output has decreased by 6 db. The non-reactive component of the output impedance is then between 580 and 620 ohms.

The reactive component of the output impedance is due to the inductance of the output transformer and the anode choke, together with the impedance of the coupling condenser. At low-frequencies the shunt impedance of the output transformer and at high-frequencies its leakage inductance affect the reactive component, and the resultant impedance between frequencies of 50 to 6400 cycles/sec. is shown in Fig. 8. The dotted curve indicates the limits within which the vector impedance must lie to ensure that the error caused by the variation of the generator-impedance from 600 ohms, when measuring the attenuation of circuits having reactive impedance with the angles up to 45°, shall not exceed 0.2 db. The small reactive component obtained is the result of a specially designed transformer having a ratio of leakage inductance to open circuit inductance of 1 to 4,000.

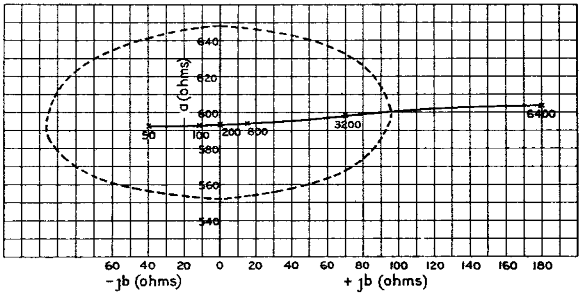


Fig. 8.—Output Impedance of Oscillator.

The Variation of Output Voltage due to Supply Voltage Variations.

One of the disadvantages of a multi-stage oscillator in which the output-voltage amplitude is dependent on the A.C. voltage generated in the initial stages is that the output is liable to vary considerably when the supply voltage varies. The variation in output voltage of the H.F. generators is reduced by ensuring that the control grid-voltage is such that the oscillation amplitude is a maximum.

The amplification variation of the intermediate amplifying stages is minimised by incorporating high resistances where possible in anode circuits. With the oscillator set up as described previously the output voltage variation is approximately 0.4 db. when the filament voltage changes 5 per cent. and about 1.3 db. when the anode supply voltage changes 5 per cent. The corresponding change in output voltage when the anode supply voltage varies 5 per cent. of the oscillators now in use in repeater stations is approximately 1.6 db. It is considered desirable that rheostats in series with the anode and filament supplies should be fitted so that these supply voltages to the oscillator may be under control. A 3-range voltmeter-milliammeter is incorporated so that the anode and filament voltages can be measured. The third range is required to measure the anode current of the detector valve.

Provision for obtaining Large Output Powers.

Whilst the oscillator has been primarily designed to give output powers up to 300 mW with an anode battery supply of 130 to 150 volts, output powers up to 10 times this value can be obtained by changing the LS6A output valve for a valve type PX25, and increasing the anode battery voltage applied to this valve to 350 or 400 volts. The harmonic content is then :—

Less than 0.3% above 300 cycles/sec. for outputs up to 0.5 watt.

Less than 1% above 40 cycles/sec. for outputs up to 1.0 watt.

Less than 2% above 20 cycles/sec. for outputs up to 2.0 watt.

These harmonic contents are obtained using an A.C. mains unit that has been designed to supply the L.T. and H.T. supplies to the oscillator.

The Operation Procedure in setting up the Oscillator.

1. Switch on and adjust supply voltages.
   L.T. voltage = 19 volts ± 10%
   H.T. voltage = 135 volts ± 15%

Although, for a constant output it is desirable to keep the supply voltages constant, satisfactory operation is obtained if the voltages are not outside the limits given.

2. Allow about ½ minute to elapse so that the indirectly heated oscillator valves are rendered operative.

3. With both the " coarse " and " fine " output controls at a minimum increase the output of the variable-frequency oscillator to a minimum by potentiometer 4.

With the beat-note frequency set at 10,000 cycles/sec. increase the negative bias of the grid of the associated oscillating valve by potentiometer 9 until the amplitude of the oscillation, as indicated by the detector current, is almost a maximum. The bias should not be increased beyond that required to give maximum oscillation.

4. Repeat the operation with the fixed-frequency oscillator, first decreasing the potentiometer 4 to zero and then increasing the " coarse " control potentiometer 5 to a maximum.

5. Reduce the " coarse " control potentiometer to zero and increase potentiometer 4 until the detector anode current increases by 0.4 to 0.6 mA.

6. Apply an output of 100 mW at a frequency of approximately 1,000 cycles/sec. and closed with 600 ohms to a frequency bridge and the bridge is balanced. The harmonic control potentiometer is varied until the optimum silence point is obtained. The valve distortion resulting in the production of second harmonic is compensated in this manner.

7. Observe the output voltage on open circuit on the level measuring set. Close the output with 600 ohms, and adjust the " impedance balance " rheostat R until the output voltage level is exactly 6 db. below the value on open circuit.

This adjusts the output impedance of the oscillator to be 600 ohms.

8. Observe the output voltage, with the output closed with 600 ohms (on a reliable voltage measuring set) over the frequency range and reduce any variation over the higher frequencies to less than 0.1 db. by adjusting the compensating condenser C_1.

The operations (3) to (8) need only be performed, say, every month or when the valves are changed in the oscillator.

9. Check " zero beat " frequency.

This should be done after the L.T. supply has been switched on for at least 10 minutes. With the " beat-frequency " condenser at zero, adjust the " zero beat " condenser until " zero beat " is obtained. Unless greater accuracy than the reading accuracy (between .1 and .2 per cent.) ± 1 cycle is required this operation need not be performed more frequently than the operations (3) to (8).

For general use, set to give the output level required and rotate the condenser dial to give the desired frequency as indicated on the dial.

The Importance of Frequency Stability and Output Purity and Constancy in Telephone Transmission Measurements.

A high degree of frequency stability of a signal generator is required in order to measure the impedance irregularities of a telephone cable. It is impossible to obtain such characteristics if the frequency is unstable and drifting. The location of faults from a knowledge of the frequency changes between successive impedance " bumps " necessitates very accurate frequency measurements to be made, and the stability and calibration accuracy of the oscillator are well worth the care and manufacturing precision that have been found necessary.

The oscillator purity greatly facilitates bridge-balancing, and becomes useful as a source of pure tone when measuring the harmonic distortion introduced by amplifiers. The importance of amplifier distortion in producing cross-talk between two or more carrier signal and audio signal channels is mentioned in this paper. The purity of the oscillator signal at very low-frequencies is of particular importance in measuring the transmission-frequency characteristics of apparatus and circuits used for music transmission. If the attenuation of the network rises rapidly at low frequencies any signal harmonics will pass through the network with relatively low attenuation and the resultant measurement of signal attenuation will be inaccurate.

Absolute constancy of output is essential where speedy and accurate attenuation-frequency characteristics of circuits are required. The introduction of an output correction factor at certain frequencies may lead to errors due to the sign of the correction factor being changed between gain and attenuation measurements.

A Direct Reading Logarithmic Scale Attenuation Measuring Set.

This instrument has been developed so that a visual indication of an A.C. signal-voltage level is obtained on an instrument with an approximately linear decibel scale. The set can be used for accurate level measurements at all audio and music frequencies. The normal range of the set is from zero to 45 db. below one milliwatt in 600 ohms, with provision to extend this range to 20 db. above 1 mW.

Principle of Operation.

The signal to be measured is amplified by means of a 2-stage thermionic amplifier and after rectification is applied to a reflecting D.C. galvanometer through a high resistance. The resistance and galvanometer are shunted by a diode biassed so that it behaves as a very high or infinite impedance when no voltage is applied across it, and so that its impedance rapidly decreases as the voltage applied across it increases. Thus the diode shunts an ever-increasing proportion of the rectified current, and the deflection of the galvanometer instead of increasing rapidly, only increases slowly as the output increases, and the resultant galvanometer scale is practically logarithmic. The simplified arrangement is shown in Fig. **9**. The A.C. input, after amplification, is applied *via* condensers 1, 2 and resistances 3, 4 to a galvanometer 5 in series with another resistance 6 through a diode rectifier 7. The galvanometer 5 and resistance 6 are shunted by another diode rectifier 8, the impedance of which can be varied by varying the bias-voltage derived from the potentiometer 9. Condensers 10 and 11 having low impedances compared with the resistances 3 and 6 form a shunt, and are incorporated to give a uniform frequency response.

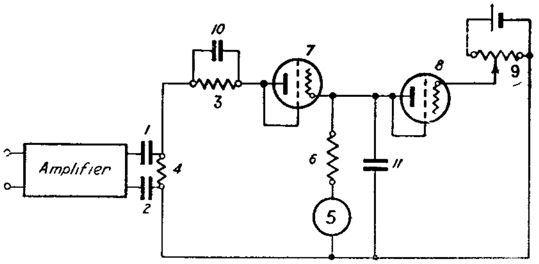


FIG. **9**.—SIMPLIFIED CIRCUIT OF MEASURING SET WITH VARIABLE RECTIFIER SHUNT.

Description of the Complete Measuring Set.

The circuit diagram of a complete measuring set is shown in Fig. **10**, and the instrument itself is shown in Fig. **11**. The input to the set is *via* a balanced and screened input transformer having an impedance

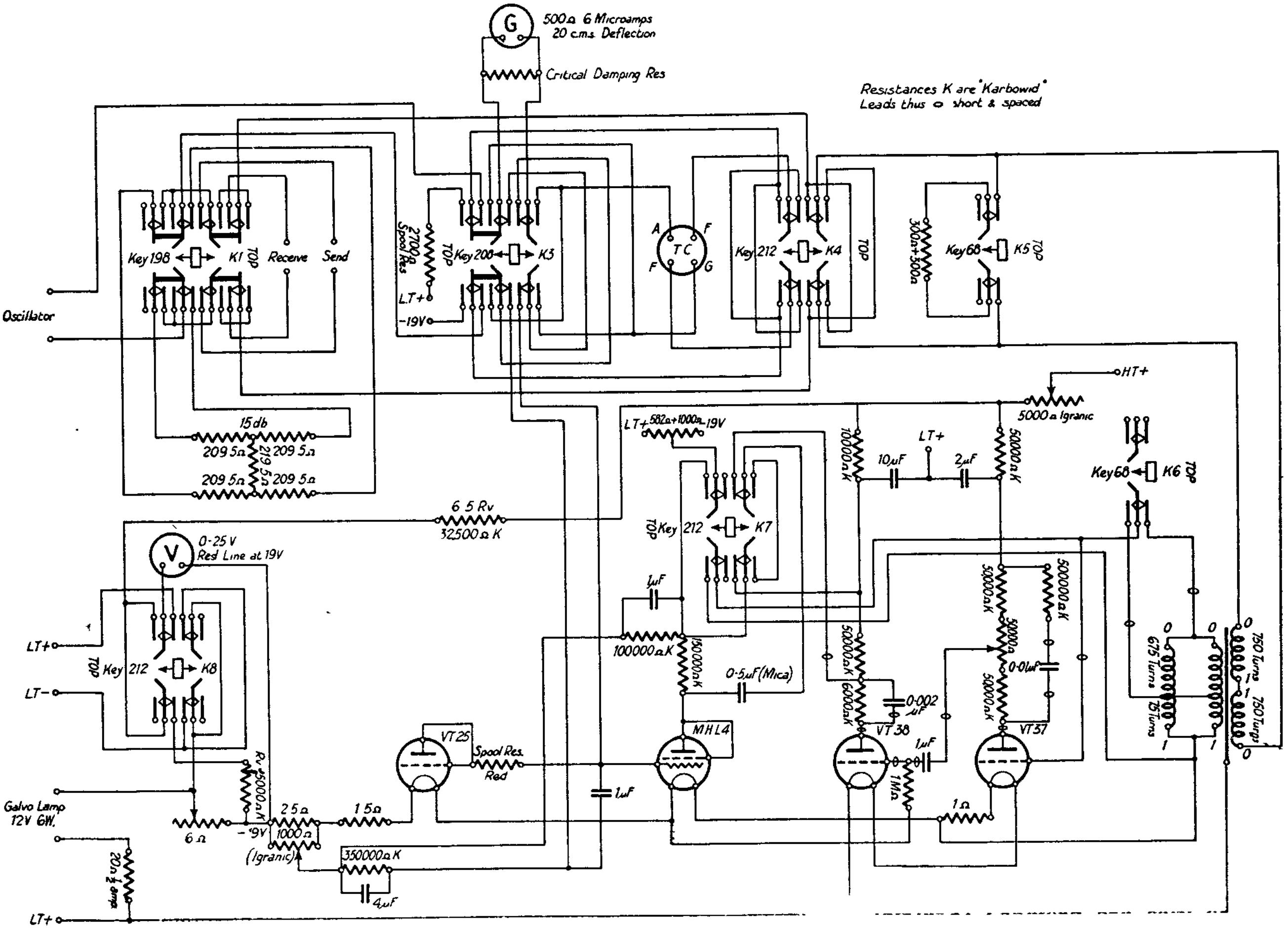


FIG. **10**.—ATTENUATION MEASURING SET (CIRCUIT DIAGRAM).

Input Balance.

The input transformer is balanced and screened so that earthing either of the A.C. input leads does not alter the instrument deflection by 0.1 db. even with an input signal frequency of 40 kilo-cycles/sec.

Other Types of Measuring Instruments incorporating a Rectifier Variable Shunt.

A dry plate rectifier can be used in place of a thermionic diode as a variable shunt. This enables a simple form of level measuring instrument to be made which is shown in Fig. **13**. No initial amplifier is incorporated. The circuit is similar in principle to that using diode rectifiers. As before the A.C. input is applied through a resistance 12 and rectifier 13 to a galvanometer 14 in series with a resistance 15, which are shunted by another rectifier 16 and condenser 17. Unfortunately, the temperature coefficients of the most suitable forms of dry plate rectifiers for use as variable shunts, are large and negative, and unless some form of temperature compensation is adopted, errors of up to 3 db. in the scale reading can be obtained with normal temperature variations (10°C to 40°C). A simple form of temperature compensation is obtained by incorporating another dry plate rectifier in the circuit. The backward impedances of certain forms of rectifiers, particularly the copper-oxide rectifiers, have very high negative temperature coefficients of the order of -7% per degree C, which is much greater than the temperature coefficient of the shunt rectifier in the forward direction. A relatively large area rectifier 18 is connected in series with the galvanometer so that the backward impedance of this rectifier replaces a portion of the resistance in series with the galvanometer. The temperature coefficient of the galvanometer 14, the resistance 15 and the rectifier impedance 18 can then be made equal to the temperature coefficint of the shunt rectifier 16. The calibration error of the instrument due to normal temperature changes can then be reduced to less than 0.5 db.

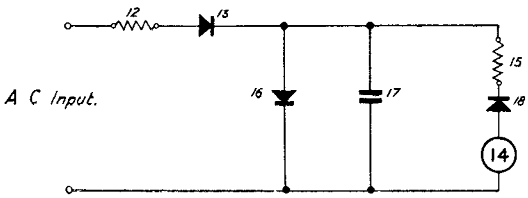


Fig. **13**.

Other forms of Logarithmic Scale Instruments employing a Variable Shunt.

Milliammeters, voltmeters and output meters, both A.C. and D.C., are now made to have a logarithmic scale using this method. An A.C. milliammeter that has a logarithmric scale over the range 0.1 to 30 mA enables currents as small as 0.025 mA to be measured with a reasonable degree of accuracy. The instrument is suitable for measuring power leakage currents. A " logscale " A.C. voltmeter with a minimum resistance of 10,000 ohms has a useful range of 0.25 to 100 volts. These instruments incorporate rectifier elements for the following purposes :—

(*a*) For normal rectification of the A.C. signal.
(*b*) To provide the logarithmic shunt to the D.C. instrument.
(*c*) To effect the necessary temperature compensation.

The advantages of logarithmic scale instruments are well-known and may be summarised :—

(*a*) A large range covered by one instrument.
(*b*) Uniformity of scale accuracy for the whole range.
(*c*) Indication of overload or transient conditions on one instrument.
(*d*) Protection of instrument under conditions in (*c*).

An interesting application of the " logscale " instrument is its use as an indicator for null-method bridge balancing. A detector unit has been developed for A.C. null methods using the rectifier-shunt principle. This consists of an all-mains valve amplifier unit connected to a rectifier instrument with logarithmic scale. The apparatus can be applied to A.C. bridges and potentiometers for obtaining a balance by visual methods, thus avoiding the use of telephones, heterodyne detectors, and vibration galvanometers for the different frequency ranges. Also, it is possible, in the case of audio-frequency apparatus, where telephone balancing has hitherto been used in separate noise-proof rooms, to use a bridge with this detector unit in a noisy workshop. Extra terminals are supplied for tuning the input transformer with a condenser for filtering the wave, an important feature for balancing impure waves with visual methods.

The frequency range is normally from 50 to 5,000 cycles/sec., but it can be adapted for carrier frequencies. The sensitivity is such that input levels from 100 micro-volts to 1 volt are recorded over the frequency range.

A Simple Constant-Output Oscillator.

Many of the maintenance tests on repeater circuits are line transmission measurements at a fixed frequency, *i.e.*, 800 cycles/sec. In these cases a power of 1 mW is transmitted to line and the incoming level at the distant end is measured. A demand has arisen for an oscillator which will supply one or more constant outputs of 1 mW, available at all times, without the necessity of checking the output level, and such an oscillator has now been developed.

Principle of Operation.

The oscillator is of the feed-back type in which the amplitude of the signal voltage applied to the grid circuit is maintained constant and independent of load and supply voltage conditions. The operation is best described in conjunction with Fig. **14**, which shows the oscillator in its simplest form. The output from valve 1 is applied *via* a step up transformer

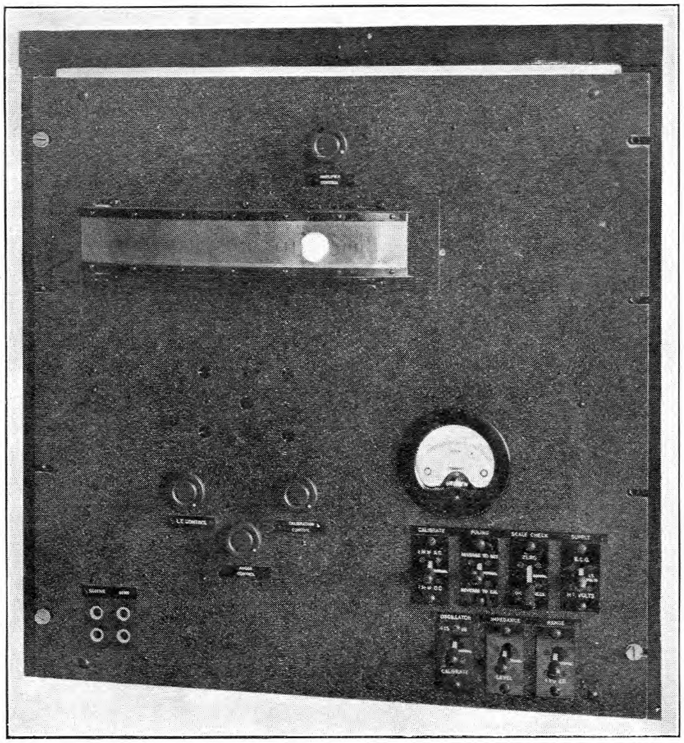


FIG. **11**.

greater than 10,000 ohms over the whole frequency range. The amplifier is resistance-capacity coupled and is compensated for frequency errors between 30 and 8,000 cycles/sec. The errors at high frequencies are mainly due to wiring and key shunt capacities. If open wiring and low capacity keys are used where necessary the high-frequency errors are solely due to the input transformer. At 12,000 cycles/sec. the the error is 0.1 db., rising to –0.6 db. at 20,000 cycles/sec. and then decreasing to –0.2 db. at 30,000 cycles/sec. and is nil at 40,000 cycles/sec.

The chief feature of the set is the method used to obtain the decibel scale, by using a diode rectifier for a variable shunt as described previously. It has been found that the scale is only slightly modified when different diode shunt valves are used, and that by associating a resistance, ranging from 0 to 1,600 ohms in series with the various diodes to be used, the scale can be reproduced over the range 0 to –30 db. to within ±0.1 db. Whilst a negligible change of scale shape has been observed over a period of 12 months' continual use, additional diode valves are provided for replacement purposes. The scale shape can be modified by changing the resistances in series with the rectifier valve and the galvanometer. A typical scale shape is shown in Fig. **12**, in which the range 0 to –30 db. is designed to be as open as possible. The galvanometer gives a full scale deflection with a current of 6 micro-amperes.

Effect of Variations of other Valves.

Facilities are provided to maintain the amplifier characteristic constant and since the signal rectifier valve is in series with an impedance of about 300,000 ohms, slight alterations of the impedance of this valve have no effect on the instrument calibration.

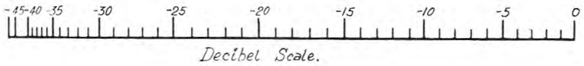
Calibration and Scale Checking.

A scale check key is provided to set the end points of the scale, " infinity " and " zero." The zero point corresponding to 1mW or full scale deflection is corrected by application of a portion of the L.T. voltage to the rectifier output circuit and adjustment of the potentiometer controlling the bias of the shunt valve. This ensures that the shunt impedance of this valve is correctly adjusted when it is shunting the maximum amount of the rectified signal current.

The level of the signal derived from the oscillator can be checked on the measuring set by means of a thermo-couple used in conjunction with the galvanometer. The thermo-couple galvanometer combination is first calibrated with a direct current of 7.27 mA derived from the low tension supply of 19v. This current corresponds to a level of +15 db. referred to 1 mW into 600 ohms. The corresponding A.C. signal level is then obtained from the oscillator, a key being provided on the set so that these conditions can be obtained. In the normal position of this key the oscillator may be applied to the measuring set through a 15 db. attenuator, and the reading obtained should be zero level. Any change will be due to amplifier variation, which can be adjusted. By changing the instrument range a reading at approximately centre scale (–20 db. referred to the low-level scale) is obtained and so the scale can be checked at this point. This alteration in range is obtained by means of a tapping on the input transformer, and is effected by throwing a key.

Power can be supplied from the set to line at any level by adjusting the oscillator output to give the desired level on the measuring set, before applying it to the outgoing line by another key.

A. With Diode Rectifiers.



B. With Metal Oxide Rectifiers.

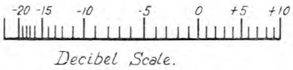


FIG. **12**.—TYPICAL SCALES OF ATTENUATION MEASURING SETS.

An additional key is provided to control the line termination, which is 600 ohms for transmission measurements and practically an open circuit for level measurements.

A set of keys provides all the facilities required in making transmission measurements.

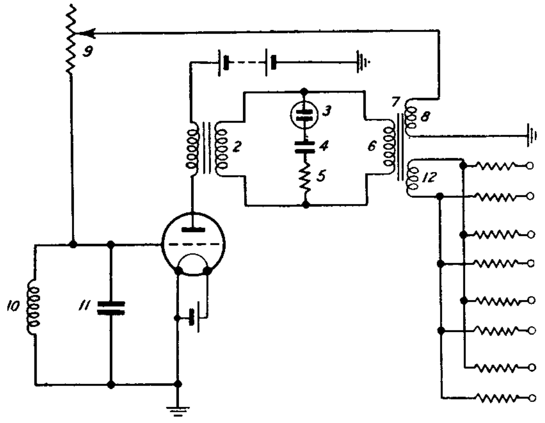


FIG. 14.—CONSTANT OUTPUT OSCILLATOR.

2 to a gaseous discharge tube (or neon lamp) 3. A condenser 4 and a resistance 5 are connected in series with the neon tube 3, which limits the voltage across the windings 6 of transformer 7, to that which will flash the tube. The condenser 4 ensures that the positive—and negative—half waves are limited to an equal extent. A portion of this limited voltage is applied *via* winding 8 through a resistance 9 to a resonant circuit 10,11 (tuned to 800 cycles/sec.), so that the voltage received across this circuit is applied to the grid of valve 1, to maintain oscillation. The value of the resistance 9 is such that the voltage obtained on the grid is just sufficient to cause the neon tube 3 to flash under the most adverse conditions; that is, with minimum supply voltages and with the maximum load. Any increase in the effective amplification of the valve 1 will only produce a slightly larger harmonic content as the neon tube will limit a slightly greater voltage. The actual voltage applied to the grid will remain constant, and the voltage obtained across winding 12 will be constant. Since the flashing voltage of a discharge tube decreases as the current through it increases, that is to say, it has a negative dynamic resistance, the resistance 5 is connected in series with the tube to ensure that the actual voltage obtained across winding 6 of transformer 7 remains constant when the current through the neon tube varies.

Further Details of the 1 *mW Oscillator.*

The oscillator is designed to operate with normal repeater station battery supplies, *i.e.*, filament battery of 21 volts, and anode battery of 130 or 150 volts. A low-impedance type valve, *e.g.*, type V.T. 39, is used so that the output load impedance is high compared with the generator impedance and changes in the load will have only a slight effect on the effective amplification of the valve. The step-up transformer to the neon tube is choke-capacity coupled to the anode circuit of the valve, the choke thereby preventing the oscillatory currents from feeding back into the anode battery. The voltage obtained across the output winding 12 of transformer 7 can be varied in small steps of about 0.15 db. by taps on the neon tube winding and by 0.9 db. taps on the output winding, which is balanced to earth. This output voltage is adjusted to be 1.55 volts and is independent of load, so that a number of output circuits can be derived from it, each being fed through 600 ohms impedance (300 ohms in each lead). In this manner 1 mW will be fed into a 600 ohm load applied to each output jack. Thus the correct condition for transmission measurement at 600 ohms impedance is established. Four output jacks are provided to enable simultaneous transmission on four different circuits to be made.

The Output Stability.

(*a*) *Effect of load changes.*

The change in the generated signal voltage across winding 12 is less than 0.1 db. when all the four 600-ohm loads are disconnected, or when one of them is short-circuited. Whilst it is possible to have all loads on open circuit, it is hardly possible to short-circuit the outputs when the oscillator is in normal use. By decreasing the feed-back resistance 9 slightly so that a more vigorous oscillation is maintained the generated voltage across winding 7 can be maintained constant when all the outputs are short-circuited. Under these feed-back conditions, however, the limiting imposed by the neon tube when the output load is reduced will cause a larger harmonic content than is desirable.

(*b*) *Effect of supply voltage changes.*

Changes of the filament and anode battery voltages of $\pm 5\%$ do not change the output voltage more than 0.05 db. A larger range of supply voltage variation—up to $\pm 20\%$—can be accommodated if the initial oscillation is sufficiently vigorous. Increased harmonic signals will be produced, however.

(*c*) *Variation of output voltage on continuous operation.*

Immediately after switching on, the output is about 0.05 db. low, and settles down to its normal value within thirty minutes. A continuous record of the output voltage over a period of one month showed that the variation was less than 0.03 db. The errors in the recording apparatus were of this magnitude, and this prevented a more accurate measurement of the output stability being made.

(*d*) *Variation of frequency with supply voltage changes.*

The frequency variation is less than 0.5 per cent. for supply voltage variations of ± 5 per cent. A greater degree of frequency stability can be obtained if required, as described later.

(*e*) *Variation of frequency with load.*

With non-reactive loads the variation of frequency when the load changes from open circuit (four loads) to a short circuit across two loads and 600 ohms across the other two loads is less than 0.05 per cent.

If all the loads are reactive $z = 600$ ohms $/45°$, the frequency change is 0.1 per cent.

It is not considered that this condition would be obtained in practice. If all four loads are of 600 ohms impedance, but two are reactive /45°, then the frequency change is less than 0.05 per cent.

(*f*) *Purity of the output signal.*

The purity of the output signal depends on the amount of signal limiting that the neon tube is called upon to exert. Both half waves are limited in amplitude to the same extent so that the odd signal harmonic frequencies only are obtained. When the feed-back resistance is correctly adjusted as described previously, the total harmonic content with normal supply voltages is about 28 db. below the 800 cycles/sec. signal. When the supply voltages are increased by 5 per cent. the harmonic content increases by about 3 db.

Oscillograms reproduced in Fig. **15** show the wave-form of the signal both controlled by the neon lamp and uncontrolled. The relative forms and amplitudes of the harmonic signals are shown, and it is of interest to note the substitution of the third harmonic for the second when the signal is controlled. Due to the discontinuous nature of the wave-form of the controlled signal, the departure from the sinusoidal shape is much more obvious than when the signal is uncontrolled. For comparison purposes the wave-form obtained from one of the oscillators now in use at repeater stations, when delivering 1 mW to the line, is given. The presence of the third harmonic is due to the push-pull amplifier. The level of the harmonic content is 33 db. below the fundamental signal level.

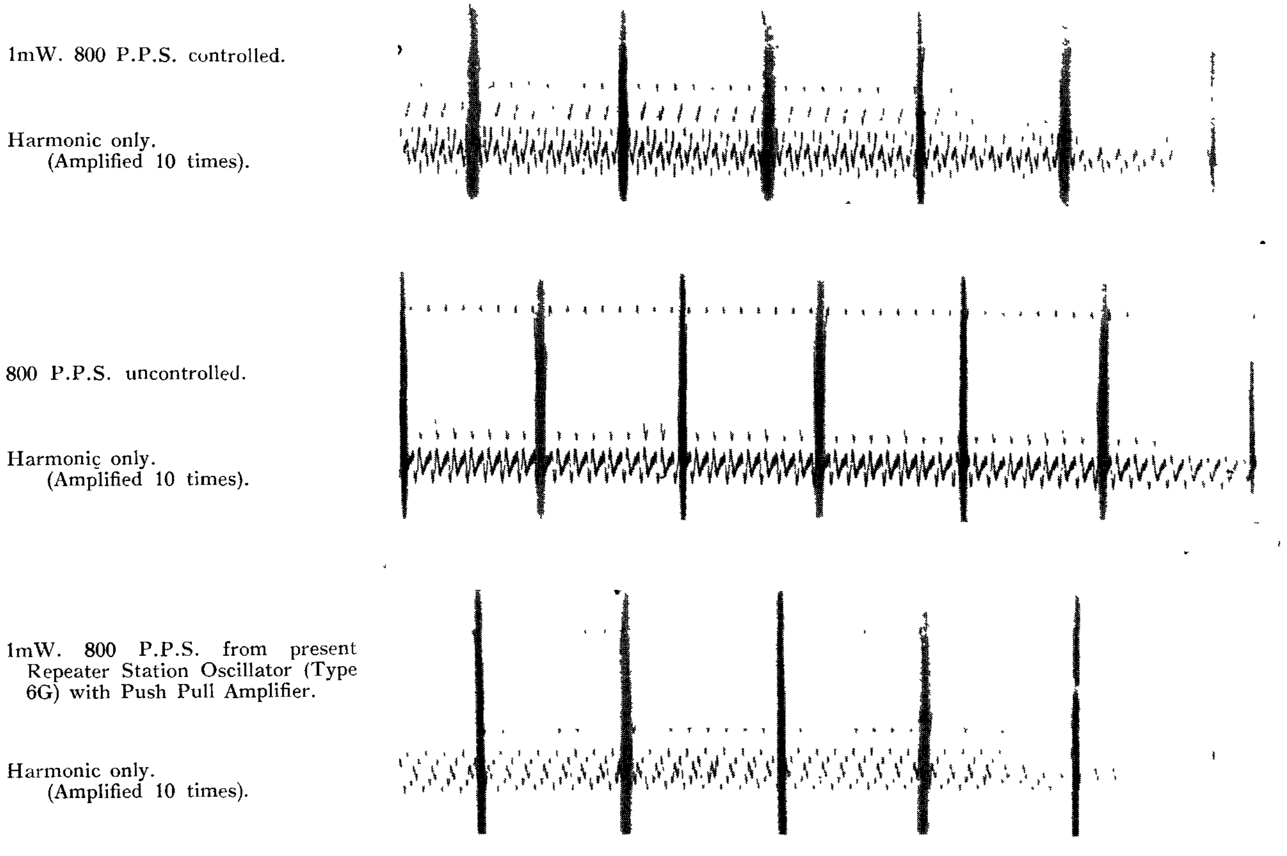


FIG. **15**.

Thus, the 1 mW controlled-output oscillator, whilst not producing a perfectly sinusoidal signal, is sufficiently pure and compares favourably in this respect with other types of oscillators in use, to meet a very definite need in the speeding-up of transmission circuit testing.

Extension of the use of Output-Controlled Oscillators.

Four separate oscillators of this type generating signals of 300, 800, 2,000 and 2,400 cycles/sec. respectively provide 4 or more independent output sources available for connection to the transmission circuits under test, *via* 4-way switches, so that 1 mW of any of the various frequency signals can be transmitted very rapidly.

Other uses of the Output-Controlled Oscillator.

(*a*) The extreme output constancy obtainable over long periods renders it very suitable as a constant source of power when variations of line attenuations are being studied.

(*b*) *As a V.F. Telegraph Signal Generator.*

The good frequency-stability, combined with the output constancy and freedom from interference from other telegraph signals derived from the same source, make it ideal for this work. The good frequency-stability is mainly due to the resonant circuit always operating under the same current conditions. If a dust core inductance (minor circuit loading coil quality) is used in the resonant circuit, together with a resistance of 1MΩ in series with the grid of the oscillating valve, a frequency variation of less than ±0.1% is obtained under supply voltage variations of ±5% and normal valve and load changes.

A Continuously Variable Audio-Frequency Neon-Valve Oscillator.

This oscillator, in which a neon-tube discharge circuit forms the oscillatory source has been developed as a simple and cheap form of instrument, which can be direct reading and enables a continuously-variable frequency signal to be obtained.

Principle of Operation.

The oscillatory circuit, shown in Fig. **16**, consists of a 3-electrode valve 1, with a resistance 2, approximately equal to its anode impedance in the valve anode circuit. The anode is connected *via* a neon discharge tube 3 to the grid and is shunted by a variable condenser 4. A high resistance 5 is connected from the grid to a point of negative potential referred to the valve-cathode, so that if no current flows *via* the neon tube through the resistance 5, the grid potential of the valve is such that no anode current flows from the anode battery through resistance 2. Oscillations are then produced in the following manner :—

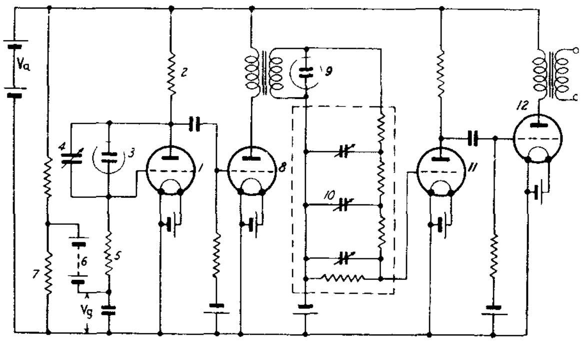


FIG. **16**.—" NEON-VALVE " OSCILLATOR CIRCUIT. (DIAGRAMMATIC).

With no current through resistance 2, the voltage across the neon tube equals the total anode and grid voltages $V_{an} + V_g$. The tube will then flash, and the resultant current flowing through resistance 5 will cause the grid to attain a less negative potential referred to the cathode and anode current will flow through resistance 2. The voltage across the neon tube falls and the tube extinguishes with a relatively low voltage across the condenser 4. The current through resistance 5 now decreases as the voltage across condenser 4 restores to normal, so that the valve grid-potential becomes more negative. This results in a reduction of the anode current, and the voltage across the neon-tube, therefore, increases until it attains the flashing voltage, when the cycle of operations is repeated. The frequency of the oscillation depends on the rate of discharge of the condenser 4 through the resistance 5. By making the condenser continuously variable, e.g., a variable air condenser (0.001 micro-farads max.), a 10 to 1 frequency range can easily be obtained. The actual range can be changed by varying the resistance 5.

Effect of Anode Supply Voltage on Frequency of Oscillation.

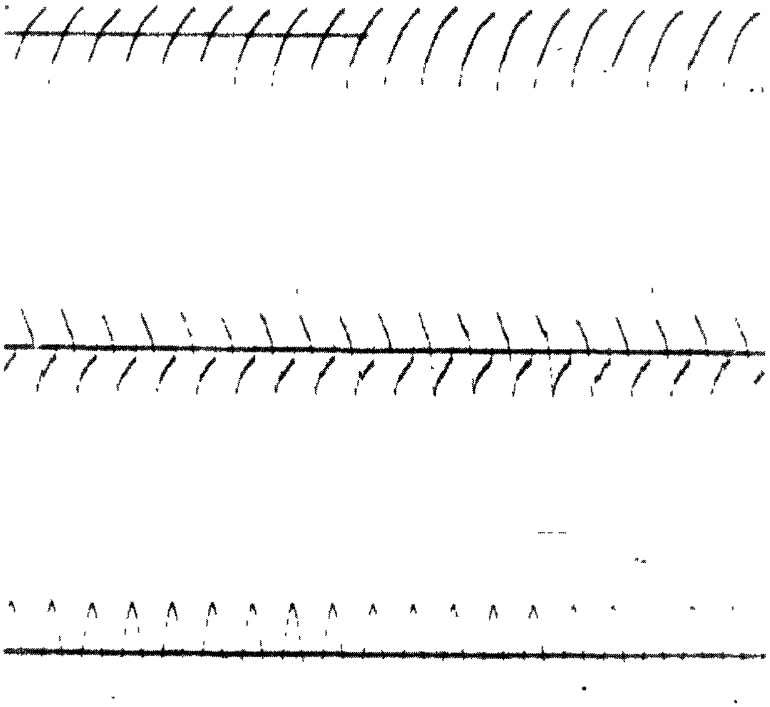
If the supply voltage increases a slight increase in the oscillation frequency occurs. This can be compensated by deriving the normal grid-bias potential from a battery 6, the positive terminal of which is connected to a potentiometer 7 across the anode supply voltage. When the anode supply voltage increases the negative grid-voltage applied to the valve is decreased so that the mean anode current through the resistance 2 is increased. By suitably selecting the tapping point of the potentiometer 7, the increase in the voltage drop across the resistance 2 can be made to compensate for the increase in anode supply voltage. In this manner, a change of less than 1% in the oscillation frequency occurs when the anode voltage changes ±10 volts.

Wave Form and Purification of the Generated Signal.

The wave form of the current through the resistance 2 is saw-toothed (Fig. **17**(*a*)). After amplifying by valve 8 (Fig. **16**) the signal is applied to a step-up transformer across the secondary winding of which is connected another neon discharge tube 9 so that the voltage produced is limited to the flashing voltage of the tube. The harmonic content is slightly improved and the signal voltage obtained is constant at all frequencies. The wave form is shown in Fig. **17**(*b*). The signal across the neon discharge tube is now applied to a 3-stage resistance-capacity filter 10 of which the series resistance arms are proportional to the resistance 5 and the shunt capacity arms are varied in conjunction with the capacity 4 controlling the generated frequency. The attenuation of the filter to any signal-frequency generated is approximately constant, and if this attenuation is large (between 10 and 20 db.) then the attenuation to the second harmonic frequencies will be at least 15 db. greater. The higher harmonics will be still further reduced in magnitude. The output from the filter 10 is applied to a resistance-capacity coupled amplifier valve 11 and finally to an output valve 12. The valves 8 and 11 are used as buffer stages to ensure that the loads taken from the oscillatory circuit and the filter respectively are constant.

The Design of a 3-Range Oscillator (50 *to* 6,000 *cycles/sec.*).

An oscillator with a frequency range of 50 cycles/sec. to 6,000 cycles/sec. utilising three ranges has been developed. A 5-gang variable air con-



(*a*) Wave Form of Generated Signal.

(*b*) Wave Form after Limiting Signal Amplitude with Discharge Lamp.

(*c*) Wave Form after Limiting and Filtration.

FIG. 17.—WAVE FORM OF " NEON-VALVE " OSCILLATOR.

denser is used of which one unit controls the frequency of oscillation, three units are incorporated in the filter and one unit is used to couple the oscillatory circuit to the amplifier valve when the " medium " and " high "-frequency ranges are in use. This eliminates very low-frequency extraneous signals produced in the oscillatory circuit and which would be readily transmitted by the low-pass filter. A 3-range switch controls the resistances in the filters together with the frequency range resistance in the oscillatory circuit.

Calibration of the Oscillator and Method of Adjustment.

The oscillation frequency is dependent on the grid-bias voltage of the oscillatory valve as well as on the value of the condenser 4 and the discharge resistance 5. The grid-bias voltage is therefore used as a calibration adjustment. A fixed-frequency bridge to balance at a known frequency of about 800 cycles/sec. can be inserted in the oscillator output. For the original calibration of the oscillator to be correct the bridge should balance with the frequency-control condenser set at a pre-determined " red line." Balance is obtained by varying the grid-bias voltage, either in coarse steps by changing the grid-bias battery voltage, or by a fine adjustment of the tap of the potentiometer connected across the anode battery supply. The oscillator calibration over the whole scale with the three ranges is then correct. The calibration is independent of the oscillatory valve provided that this simple adjustment is first made.

Typical Frequency Calibration.

The oscillator-frequency calibrated against the condenser setting for the three ranges is as follows :—

Dial Setting.	Frequency (cycles/sec.).		
	Low Range.	Medium Range.	High Range.
0	48	218	1780
20	67	295	2420
40	93	420	3500
60	143	620	5100
80	236	1050	6100
100	545	2390	—

The oscillations cease when the frequency reaches 6,500 cycles/sec. and the oscillatory discharge through the neon tube is replaced by a steady discharge.

The output variation with frequency with a load of 600 ohms is shown in Fig. **18**. The maximum power output is approximately 200 mW, but this can be increased by modifying the final stage valve and the anode voltage supply.

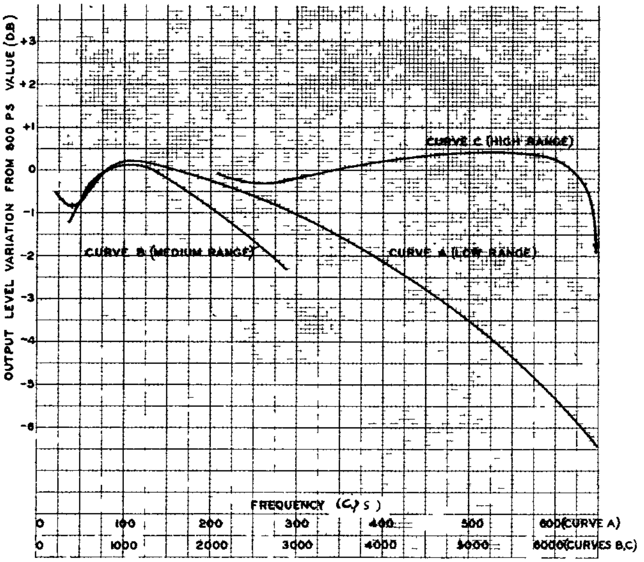


Fig. **18**.—Output Frequency Characteristics of "Neon-Valve" Oscillator.

Harmonic Content.

The level of the harmonic content of the oscillator is 26 to 30 db. below the fundamental signal level. The wave form is shown in Fig. **17**(*c*).

Uses of the "Neon-Valve" Oscillator.

The facility for obtaining a continuously-variable frequency signal has hitherto only been available in heterodyne-type oscillators. It is difficult to obtain good frequency stability from an inexpensive form of heterodyne oscillator, and the "neon-valve" oscillator provides a cheap and reliable substitute for use where the cost of the apparatus is to be kept small.

Part II.—Apparatus Associated with Speech Signal Transmission.

The Reduction of Valve-Amplitude Distortion in Repeaters.

This may be termed straightening the valve characteristics. All normal types of 3-electrode valves produce considerable distortion when operating as power amplifiers, due to the curvature of the anode current-grid voltage characteristic. A typical valve characteristic is shown in Fig. **19**. The load impedance is 10,000 ohms. If the valve produces no distortion equal positive and negative changes of grid-voltage about the normal grid-voltage bias point 0 must produce equal positive and negative changes in the anode current through the load resistance. But it is seen that a positive change of grid-voltage produces a larger anode current change than a similar negative change of grid-voltage. This effect can be corrected :—

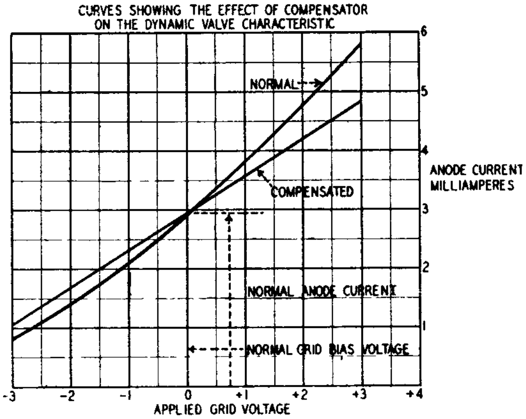


Fig. **19**.

(*a*) By reducing the positive grid-voltage change as compared with the negative grid-voltage change before applying the signal voltage to the grid of the valve.

(*b*) By reducing the large positive change in load current obtained in the anode circuit, by increasing the load impedance for positive current as compared with the load for negative current changes.

If method (*a*) is used the full output power of the valve is available, but the amount of compensation introduced is independent of load changes, whilst it is well known that the distortion produced in a valve is a function of the anode load impedance.

Method (*b*) can be made to take account of the load impedance changes, but it slightly reduces the output power of the valve.

(*a*) *Valve-Distortion Correction by Grid-Voltage Compensation.*

The source of A.C. signal, usually the winding (Fig. **20**) of a transformer, is applied to the grid of the valve 2 *via* a metal-oxide rectifier 3 shunted by a resistance 4. A load resistance 5 is connected in the grid circuit as shown. Typical values for the combination are :—

Rectifier	3	W6 (Westector)
Resistance	4	0.5MΩ
,,	5	1.0MΩ

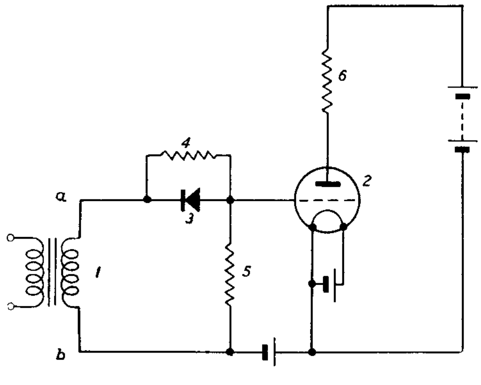


Fig. **20**.—Valve Distortion Corrector in Grid Circuit.

The actual values will depend on the total voltage swing, the type of valve, the load impedance, the anode voltage and the normal negative grid-bias priming potential. In general, these particulars are known.

Principle of Operation.

When an instantaneous positive signal voltage is obtained across the terminals *a b* of winding 1 it is applied *via* resistance 4 across the resistance 5, and, since the high backward impedance of the rectifier 3 has but little effect on the total impedance in series with the grid resistance 5, the actual signal voltage applied to the grid across the resistance 5 is reduced. When a negative signal voltage is obtained across the terminals *a b* of winding 1, however, the rectifier 3 has a low resistance and practically all the signal voltage is applied across the grid resistance 5. Thus, by choosing suitable values for the components 3, 4 and 5, the positive anode current change through the load resistance 6 can be made equal to the corresponding negative anode current change derived from equal grid-bias voltage changes from the transformer winding 1. A comparison of the corrected and uncorrected characteristics is shown in Fig. **19**.

(b) Valve-Distortion Correction by Anode-Current Compensation.

In principle this is the same as (*a*). The arrangement is shown in Fig. **21**. The compensator, comprising the rectifier 2, shunted by a resistance 1, is in series with the load impedance 3. If the load impedance rises the valve will deliver a smaller signal current to the rectifier and both the valve distortion and the compensator correction are reduced. Thus to a large extent the compensator is independent of the load impedances. The following values of the compensator components have been found satisfactory for use in conjunction with repeater valves type VT.68 used under normal conditions in 4-wire repeaters :—

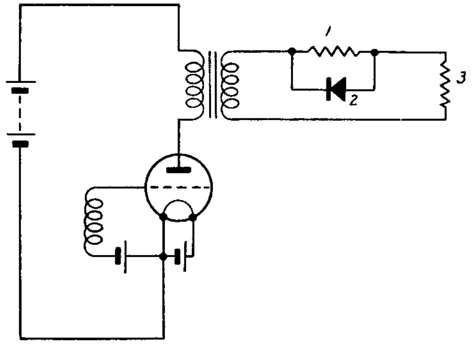


Fig. **21**.—Valve Distortion Corrector in Output Circuit.

Rectifier—Westinghouse 2 elements/50 mA type.

Shunting Resistance—120 ohms.

The nominal output load is 600 ohms.

The values of the compensator components are but slightly changed when different type valves having the same output power are used, and these values may be used with any repeater type valves which have an anode impedance of 5,000 to 6,000 ohms.

The Phase Change between the Source of Distortion and the Distortion Corrector.

Any change of phase difference between the fundamental signal-frequency and the harmonic signals produced that occurs between the valve anode circuit and the distortion-corrector will prevent complete compensation from being obtained. This change of phase difference is due to the grid-kathode capacity, if the compensator is connected in the grid-circuit, or to the leakage inductance of the output transformer and the presence of a reactive load, if the compensator is associated with the output circuit of the valve. Usually any change of phase difference may be partially corrected by shunting either the compensator network or the load impedance with a condenser or an inductance. Whilst complete compensation over a large frequency range cannot be obtained by these means, the error due to changes of phase difference over the required frequency range is usually less than the error normally associated with incomplete compensation due to valve-characteristic variations from those of an average valve.

Uses of the Valve-Distortion Corrector.

(a) To decrease the harmonic content of amplifiers.

A reduction of at least 10 db. in the harmonic content of 3-electrode valve amplifiers can be obtained, provided the load-impedance is reasonably constant over the required frequency range, such as the impedance of a telephone cable connected to the repeater output. This decrease in harmonic enables the negative grid-kathode bias voltage to be increased without increasing the valve distortion. This results in :—

1. A reduction of the normal valve-anode current by one-third.
2. Doubling the power output of a valve when producing 2 per cent. harmonic.

The relation between harmonic-content and power-output for a repeater valve type VT.68 is shown in Fig. **22**. The compensator was applied to the grid

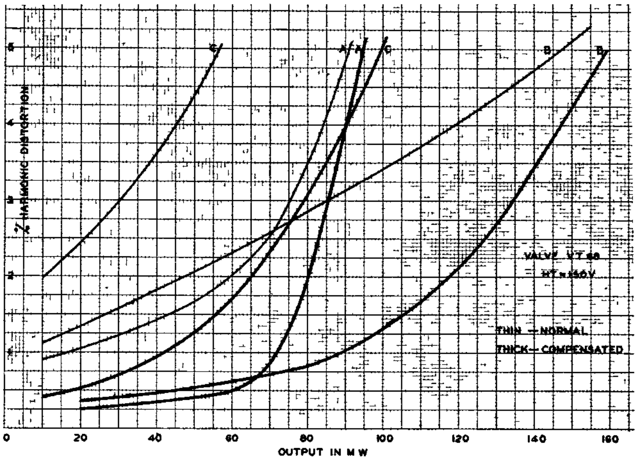


Fig. **22**.—Harmonic Content of VT68 Valve with Harmonic Compensator.

of the valve. The thick and thin curves refer to the harmonic obtained with and without the compensator respectively. The three sets of curves were obtained with normal grid-bias voltages of 5, 7 and 9 volts to produce steady anode currents respectively of (*a*) 14 mA (correct nominal anode current); (*b*) 10 mA; (*c*) 6 mA.

In Fig. **23** the harmonic content in decibels below the fundamental is related to the output in decibels referred to 1 mW for the repeater valve VT.25. (L.S.5 type). These curves were obtained at frequencies from 300 cycles/sec. to 6,000 cycles/sec. in conjunction with a toll-circuit amplifier. When the normal valve distortion is corrected the effect of overloading due to grid-current distortion is very marked.

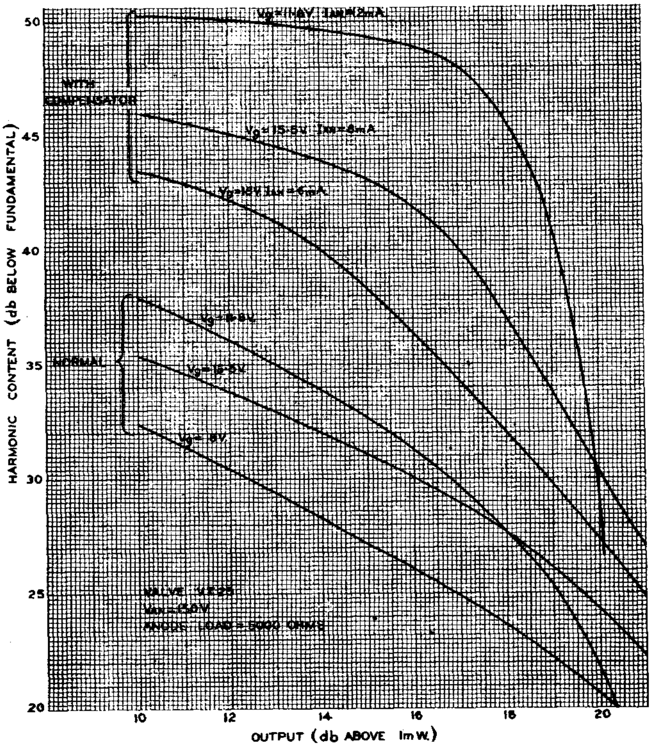


FIG. **23**.—HARMONIC CONTENT FROM VALVE VT25 WITH DISTORTION COMPENSATOR.

The effects of valve changes and variations of supply voltages on the amount of harmonic correction obtained with a pre-determined compensator network are summarised below :—

Tests were made with 12 valves P.O. type VT.24 (L.S.5) and 12 valves P.O. type VT.75 (4019A). The corrector was applied in the grid-circuit of the valve and consisted of a W6 type rectifier shunted by 0.2MΩ. The grid load was 1MΩ. An additional condenser of 300 micro-microfarads in the case of the VT.75 valves and 230 micro-microfarads in the case of the VT.24 valves was shunted across the rectifier to compensate for the grid-anode capacity of the valve.

(1) *The Effect of Valve Changes.*

H.T. voltage = 130v
Grid-bias voltage—V.T.75 ... −8v
V.T.25 ... −9v

Improvement in harmonic content.	V.T.25.	V.T.75.
Max.	14 db.	16 db.
Mean	12 db.	15 db.
Min.	10 db.	12 db.
Mean Harmonic (uncompensated)	−32 db.	−33.5 db.

NOTE :—The output from the valve was 10 mW in all the tests.

(2) *The Effect of Anode-Voltage and Grid-Voltage Changes.*

With anode-supply changes of ±10 volts or a grid-voltage change of ±1 volt a mean improvement in harmonic content of 10 db. is still obtained.

(3) *The Effect of Changes in the Compensator Components.*

The resistance shunting the rectifier can be varied ±25 per cent. from its normal value and a minimum improvement of 10 db. in harmonic content is still obtained. Similarly the shunting capacity can be varied by ±30 per cent. to obtain the same improvement.

(*b*) *To Reduce Distortion and Cross-talk* due to rectification in repeaters used as common amplifiers in a multi-channel carrier-current telephone system.

If a normal type telephone repeater is used for the simultaneous transmission of audio- and carrier-frequency signals, interference between the audio carrier frequencies is liable to occur due to the non-linearity of the valve characteristics. The most important effect is the production of an unduly high level of cross-talk from the " carrier " circuit to the " audio " circuit due to rectification occurring in the valve amplifier. Even when the carrier-frequency transmission system is of the suppressed carrier type the cross-talk is excessive and the adoption of standard repeaters can only be tolerated if the valve distortion is reduced. The results obtained when the distortion corrector is applied in a short experimental audio and carrier circuit are as follows :—

Circuit. Carmarthen to Haverfordwest, 20 lbs. star-quad, equalised up to 5,500 cycles/sec.
Loading. 30 mH at 1.136 miles spacing.
Repeaters. Toll circuit amplifiers at Carmarthen and Haverfordwest.

Reference Volume and Volume Indicator.

Throughout the whole of the tests speech was maintained at reference volume, a volume indicator being in parallel with the telephone. The volume indicator was calibrated against a Western Electric Volume indicator at the Transatlantic Terminal by a number of speakers. In practice the extensive records taken at the Transatlantic Terminal show that reference volume is seldom, if ever, realised at a trunk terminal. Reasonably loud speech is 10 db. below reference volume which is approximately 5 db. above the S.F.E.R.T. standard.

Cross-talk. Carrier to physical circuit.

Repeater output (db. above speech level).	Cross-talk level (db.).		
	Without Corrector.	With Corrector. (1)	(2)
+ 10	– 45	– 42	– 44
+ 5	– 46	– 46	– 52
0	– 43	– 54	– 58
– 5	– 46	– 60	– 66

(1) Transmitting from Haverfordwest to Carmarthen

(2) Transmitting from Carmarthen to Haverfordwest.

The cross-talk without the corrector was the same when measured at either end of the circuit, but the amount of correction obtained when transmitting from Haverfordwest to Carmarthen was low, as the line impedance associated with the output of the repeater at Haverfordwest was very variable with frequency, due to the final half loading-coil not being present, and the correct phase relationship between the distortion and the distortion compensation could not be obtained. The compensator consisted of a 2 element, 50 mA type Westinghouse rectifier shunted by 120 ohms, connected directly in series with the line in the repeater output circuit. At the Carmarthen end where the cable was correctly loaded the compensator was shunted by 0.10 microfarads. These values of the compensator components had previously been determined in the laboratory, and represent the mean values to give the maximum reduction of harmonic. Measurements of the cross-talk obtained using various values of the compensator components confirmed that these values also give the maximum cross-talk reduction.

With repeater output levels of + 10 and + 5 db. above the line terminal level slight overloading occurred in the repeater valve producing excessive distortion. With a zero output level the cross-talk is fairly satisfactory, although it would be too large without the addition of the distortion compensator.

A Summary of the Uses of the Valve-Distortion Corrector.

(1) To improve the wave form of 3-electrode valve oscillators.

(2) To decrease the anode current of amplifier valves by one third and obtain approximately twice the output power for any given percentage of harmonic up to 3 per cent.

(3) To decrease the harmonic content of existing valve amplifiers and repeaters by 10 db.

(4) To reduce distortion due to modulation and rectification in carrier-current telephone systems.

(5) To improve the reading accuracy of all A.C. bridges in which the signal source is a valve oscillator and in which the impedance under test is a function of frequency.

Some New Voice-Operated Switching Circuits

A new method of voice-operated switching has recently been developed in which the switch consists of a variable attenuation network which is inserted in an A.C. signal circuit, and its loss is changed by means of a small controlling direct current applied to it. This attenuation network, which can be used effectively in any telephone circuit employing voice-operated switching is as follows :—

The Rectifier Attenuation Network.

This comprises series and shunt elements consisting of rectifier units preferably of the dry-plate metal-oxide type.

One form is shown in Fig. **24**(*a*). The signal transmission circuit is from A to B. The direct current controlling the network attenuation is fed into the network circuit at points C, D. When it flows in the direction of the arrow at C, it will be applied to the rectifier R_1 so that the impedance of the rectifier, both to A.C. and D.C. signals, is low. At the same time it will be applied to the rectifier R_2 in the reverse direction, so that the impedance is high. Thus the attenuation between the transformers T_1 and T_2 in the signal transmission circuit, is small. If the direction of the control-current is now reversed, the impedance of the rectifier R_1 becomes large, and that of rectifier R_2 becomes small, so that the attenuation between the transformers T_1 and T_2 is large. It will be noted that the rectifier network offers a low-resistance path to the control-current in both directions.

Fig. **24**(*b*) shows a balanced form of attenuation network so that the impulses of the control-current are not introduced into the signal circuit, and the inductances of the windings of the transformers T_1 and T_2 do not prevent a rapid change of the control-current taking place.

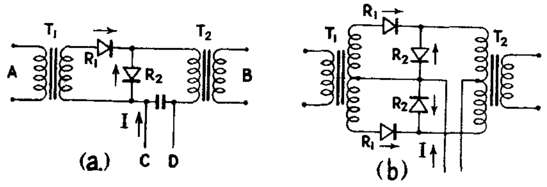


Fig. **24**.—Rectifier Attenuation Networks.
(*a*.) Unbalanced type.
(*b*.) Balanced type.

A typical attenuation-control current characteristic is shown in Fig. **25**.

The Application of the Attenuation Networks to an Echo-Suppressor.

An attenuation network is inserted in each of the two associated signal paths, preferably where the level of the speech signals is small, *i.e.*, immediately prior to the repeater input terminals. In the quiescent state a small control-current flows through

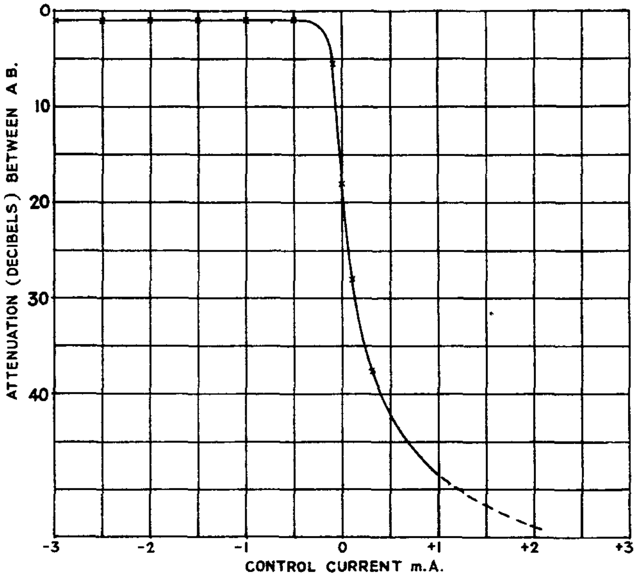


Fig. 25.

each of the networks and ensures that they both have a low attenuation. On applying an A.C. signal to the " go " circuit the control-current through both networks is simultaneously changed, and it is increased in the network in the " go " circuit that carries the signal current, and so slightly reduces its attenuation and at the same time reduces the amplitude distortion introduced by the network to a negligible amount. The control-current in the network in the " return " circuit is reduced, and reversed, and this causes a large increase in the attenuation of the associated rectifier network circuit.

The reverse conditions are obtained if the signal is applied to the " return " circuit.

The Derivation of the Polarising Network Current (Schematic).

The polarising network current is derived from a differential bridge circuit in the anode circuits of two valves on opposite sides of the repeater. The arrangement is shown in Fig. **26**.

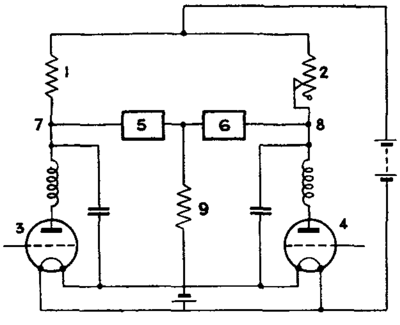


Fig. **26**.—Control Current Bridge Circuit for Ecvo Suppressor.

The resistance 1, 2 and the D.C. anode impedances of the repeater valves 3, 4 form the four arms of a D.C. bridge of which the anode-battery forms the supply voltage. The normal currents that flow through the attenuation networks 5, 6 through the resistance 9 are made equal by balancing the bridge network by adjusting the value of resistance 2.

When an A.C. signal passes through the valve 3 a portion of the signal is rectified and applied to the grid of the valve 4 to cause the grid-voltage to become positive and so increase its anode current. The potential of point 8 is reduced and a secondary current from point 7 to point 8 flows through the networks, and increases the normal current in network 5, and is in opposition to the normal current in network 6. These current changes slightly reduce the attenuation of network 5 and cause a large increase in the attenuation of network 6, associated with the " echo " signal-path and so prevent the " echo " signal from being transmitted.

The Signal Rectifier Circuit.

Fig. **27**, which shows the complete echo-suppressor equipment to be used in conjunction with a repeater, includes the signal rectifier circuit. The two series tuned circuits A and B, having resonant frequencies of 600 and 750 cycles/sec. respectively are connected across a winding of the transformer to prevent signals of these frequencies from being rectified and operating the suppressor. (This condition is required in view of the application of simultaneous 2-frequency signalling on trunk circuits, but it does not affect the fundamental operations of the suppressor). The 1/25 voltage ratio step-up transformer is tuned to have a maximum impedance, in conjunction with the shunt impedances of the series tuned circuits, at a frequency of about 1,400 cycles/sec. The rectifiers used are Westector WX6 type, having a backward impedance of between 10 and 20 megohms at 65°F., and a voltage-doubler arrangement is used to obtain maximum sensitivity and also to reduce the amount of harmonic produced by the rectifiers. The shunt loss imposed on the output circuit of the repeater by the signal-rectifier circuit is sensibly that due to the series resistance of 1,000 ohms at all frequencies, *i.e.,* 2.5 db., except near the resonant frequency of the transformer when its additional series impedance decreases the loss to about 1.5 db. If the input level to the suppressor is above about -10 db. referred to 1 mW, the transformer is shunted by the increased rectifier load caused by the valve grid-current that flows and so the shunt load across the output once more approximates to 1,000 ohms. The loss is then increased as the input level to the suppressor increases until it attains the normal loss of 2.5 db. with an input level of about 1 mW.

The rectified-signal voltage applied to the grid-circuit of the complementary repeater requires to be smoothed to prevent the A.C. component of the rectified signal from being amplified and passing out into the transmission circuit. This coupling between the repeaters results in low-frequency cross-talk about 40 db. below the level of speech signals applied to the echo-suppressor. A more elaborate smoothing circuit could be employed to reduce this

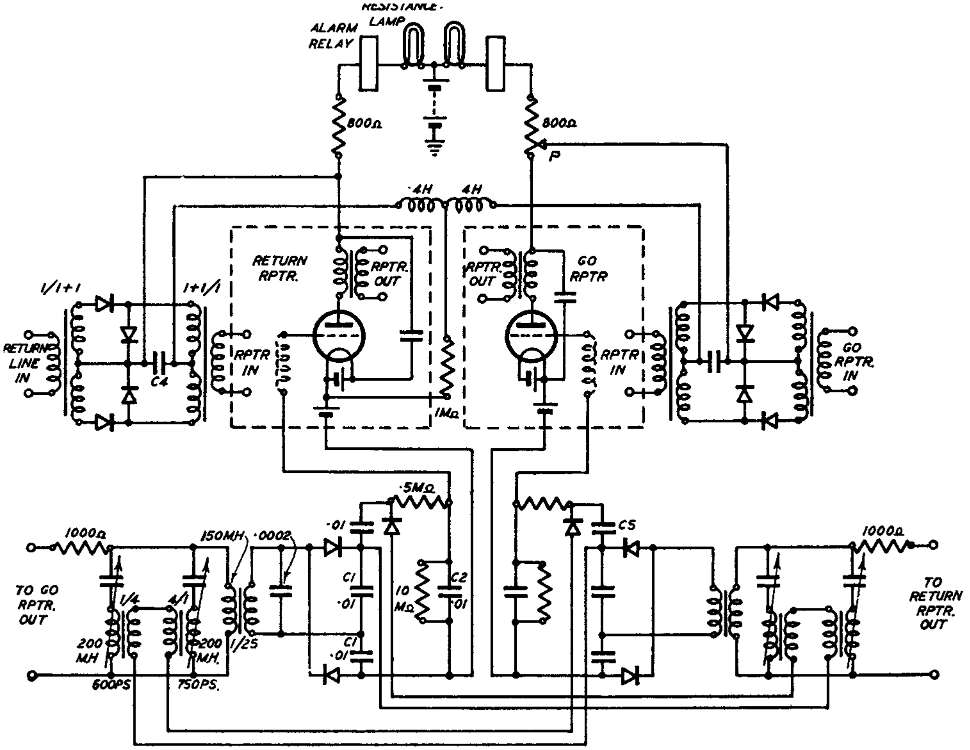


FIG. 27.—CIRCUIT DIAGRAM OF MODIFIED ECHO SUPPRESSOR INCORPORATING 600P.S. AND 750P.S. REJECTOR CIRCUITS.

cross-talk, but no real benefit would be derived from so doing.

The time the suppressor remains operative after the signal ceases depends on the value of the condensers C_1, C_2 in conjunction with the backward impedance of the associated rectifiers. With the components specified the hangover time is approximately 0.2 seconds, and is independent of the input level of the signal to the suppressor if that level is above about −5 db. referred to 1 mW due to the limitation (caused by the grid-current) of the D.C. voltage obtained across the condensers C_2.

The Differential Bridge Circuit controlling the Polarising Current.

The additional apparatus and circuit arrangements to be applied to the existing repeater are shown in Fig. **27**. The resistances in the anode circuit which form adjacent arms of the bridge from which the polarising current is derived are built up to 1,300 ohms, which includes the resistance of any relays, chokes or lamps in the anode-supply leads. The network polarising currents, which flow from the anode resistances, are adjusted to be equal in the quiescent state by varying the position of the potentiometer slider P.

Sensitivity.

Since the suppression is due to a change in anode current of the repeater valve, which change is caused by a change in the grid-bias voltage, the actual suppressor-sensitivity is proportional to the mutual conductance of the associated repeater valve. With the present P.O. repeater valve having an impedance of 5,000 ohms and an amplification factor of 7, attenuation of 20 db. in the associated complementary circuit is produced by a signal (F = 1,400 cycles/sec.) 17 db. below 1 mW applied to the suppressor input terminals. The sensitivity-suppressor attenuation curve is shown in Fig. **28**. A typical sensitivity-

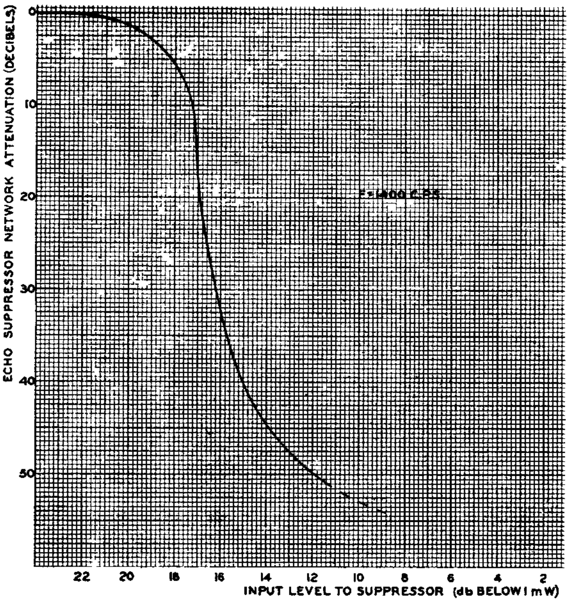


FIG. 28.—ECHO SUPPRESSOR-SENSITIVITY/INPUT LEVEL CHARACTERISTICS.

frequency curve (without 600 cycles/sec. and 750 cycles/sec. rejector circuits) for 20 db. suppressor attenuation is shown in Fig. **29**, curve A. The sensitivity-suppressor attenuation curve is far more constant than in the grid-biasing anode-current suppression type as the relation between the polarising network current and the network attenuation is practically identical for all rectifiers of the type used, whilst a 5 db. difference in the sensitivity of the valve grid suppressor can easily be obtained due to the valve characteristic varying at large negative grid-voltages. This factor is important when liability of false operation on zero attenuation circuits is investigated.

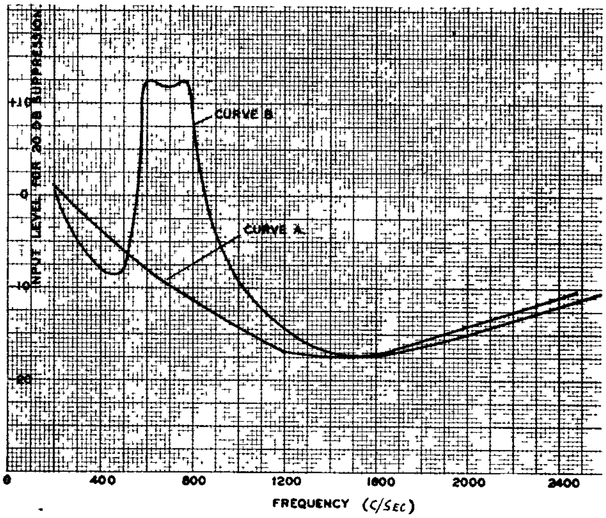


FIG. **29**.—ECHO SUPPRESSOR-SENSITIVITY/FREQUENCY CHARACTERISTICS.

The suppressor sensitivity has been found to be adequate for effective echo-suppression on all zero-attenuation circuits when the input to the suppressor is obtained from the output of a repeater at a + 10 db. level.

Margin against False Operation.

False operation or operation of the complementary suppressor by echo-signal currents, which causes clipping of the main-signal current has been found to occur with the valve grid-suppressor when operating on zero attenuation circuits. Under these conditions the level of the echo-current applied to the complementary echo-suppressor may be practically equal to that of the normal signal current. If the latter current is not quite large enough to cause signal suppression in the complementary circuit and the sensitivity of the complementary suppressor is greater this suppressor will operate and cause clipping or fading. Unequal or incorrect levels at the echo-suppressor input terminals will cause unequal effective suppressor-sensitivities. These incorrect levels are less likely to be obtained using terminal suppressors than centre-circuit suppressors, as the terminal level conditions are fixed and checked frequently.

The operation of the differential valveless-suppressor is as follows :—

The application of a signal to one repeater A to produce a change in the network current of i, which change is insufficient to cause appreciable attenuation in the complementary circuit of repeater B, will cause an increase of i in the current through the network associated with repeater A. The echo-signal current applied to repeater B will now have to produce a change of at least $2i$ in the polarising network current before the current through the network associated with repeater A is decreased sufficiently to cause signal attenuation in the main signal path through repeater A. Thus the level of the echo-current must be 6 db. above the level of the main signal-current as compared with a value only equal to it in the case of a non-differential type of echo-suppressor, before false operation can occur. This additional margin has been found in practice to exist and the level of the echo-signal on a " zero " attenuation circuit with a loss round the termination of 12 db. has to be raised 6 db. above the normal level before false operation at low signal strengths occurs.

Speed of Operation, Hangover Time and Limitation of Hangover Time.

The hangover time has been adjusted to be about 0.2 seconds, so that when the echo-suppressor is used on a circuit over which " Telex " is used, the " Mechanical reply " to the " Who are you " signal, which occurs after a delay of 0.310 seconds, is not mutilated. This hangover time should be adequate for all British circuits, even when using terminal-suppressors.

With a smoothing resistance R of 0.1 megohms the cross-talk between repeater outputs *via* the rectified signal-path to the valve grid is approximately 35 db. With a resistance R of 0.5 megohms the corresponding cross-talk is approximately 40 db. Whilst a resistance R of 0.1 megohms gives a slightly shorter operating time, the value 0.5 megohms is recommended for normal use.

The speed of operation and hangover time of the echo-suppressor with different values of the smoothing resistance R are shown in the following table.

Frequency of operating signal = 1,300 cycles/sec.

The hangover time is regarded as the time taken by the signal to attain approximately 0.8 of its normal amplitude.

Level of signal applied to input of suppressor in db. above 1 mW.		Time (milliseconds).		
		Operating.		Hangover.
	R	0.1MΩ	0.5MΩ	
+ 10		1.5	2.5	210
0		5	6	195
− 5		8	10	180
− 10		13	16	160

The hangover times are unchanged when R = 0.1MΩ.

These operating times are very much smaller than are obtained using the valve-suppression type of suppressor in which the operating time ranges from 30 milliseconds at a level of +10 db. to 55 milliseconds at a level of –10 db. referred to 1 mW.

Oscillograms showing the operating and hangover times are given in Fig. **30**.

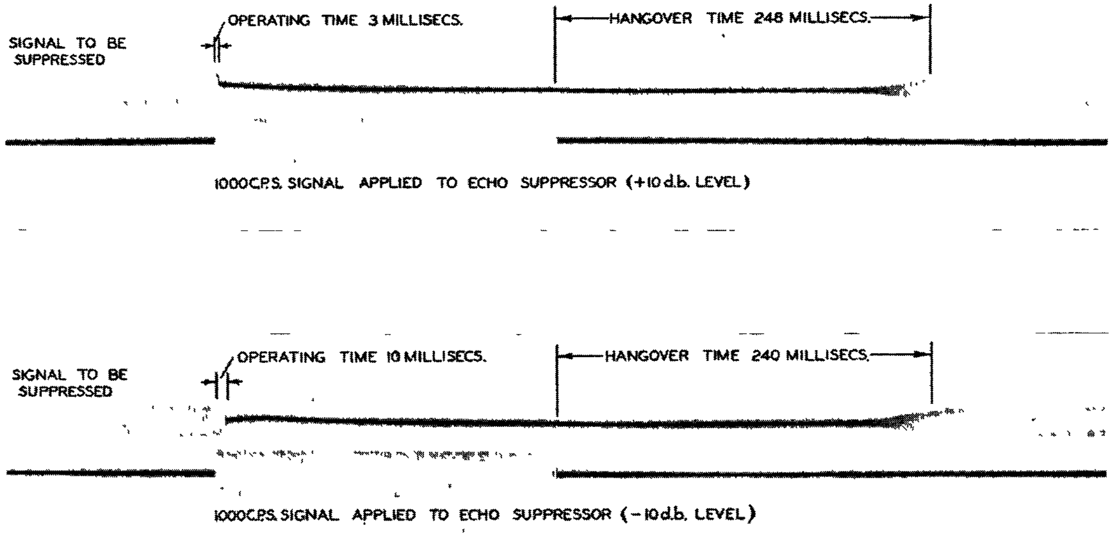


FIG. **30**.

Operation as a Terminal-Suppressor.

When used at a terminal station a 6 db. pad is inserted in the 2-wire circuit adjacent to the suppressor. The output of the " return " repeater is then at a +10 db. level to give a " zero " overall circuit, and the input of the " go " repeater is at a –10 db. level. Furthermore, the level of the signal from the 2-wire extension, applied to the output of the " return " repeater tending to produce operation of the wrong suppressor, is –10 db., as compared with the level of +10 db. obtained at the output of the " go " repeater and which is applied to the suppressor to be operated. Thus the signal tending to cause false operation is very much smaller than the main signal and it results in a negligible change of the anode-current of the valve carrying the signal current.

The use of terminal-suppressors in place of centre-circuit suppressors reduces maintenance. All modifications necessary when the circuit is to be used for V.F. telegraph or for any one-way transmissions can be made at the terminal stations. The line levels at which the suppressors are operating are not liable to alter so much as if they were in the centre of the circuit. For example, the normal lining up of the circuit to " zero level " must ensure that the " return " repeater output level is +10 db., whilst the level changes of the " go " repeater output are caused only by changes in the gain of that repeater, as the signal only passes through that repeater after entering the 4-wire circuit.

The Effect of the Echo-Suppressor Load on the Repeater Output.

The output voltage of the repeater is reduced by 2.5 db. due to the echo-suppressor load. At the same time the anode-voltage is reduced by approximately 6 volts due to the voltage drop in the anode-feed resistances. Either of these losses can be reduced at the cost of reduced sensitivity. Alternately if a valve is used in the repeater with a higher mutual conductance, and preferably with a lower impedance so that the effect of the shunt load of the suppressor is less marked, the sensitivity of the suppressor can be maintained, or even increased, and the normal power output of the repeater can be retained.

The Effect of the Echo-Suppressor Load on the Stability of the Associated Circuit.

The shunt loss imposed by the echo-suppressor load across the output of the repeater is slightly less for low output levels at a frequency of about 1,300 cycles/sec. than at other levels. There is, therefore, a slight loss of stability margin (about 1 db.) at this frequency. In general this is unimportant for unless the " howling " frequency of the circuit is near 1,300 cycles/sec. no change in the stability margin is obtained. The stability is mainly important in that the circuit should not go into oscillation when one of the two-wire extensions is on open circuit whilst a subscriber is listening at the other end. With a subscriber's instrument and a short extension line connected to the 2-wire termination, the balance obtained is generally such that self-oscillation first occurs at a relatively low frequency, as the loss round the 4-wire termination is least at low frequencies and can be actually a maximum near 1,400 cycles/sec. This condition was found to exist when various types of subscribers' instruments were used with typical short 2-wire extensions. Thus the echo-suppressor has no effect at all on the stability of a circuit as the normal low-frequency stability which controls the howling frequency is unaffected.

If the shunt-loss imposed by the echo-suppressor load is decreased by increasing the resistance in series with the tuned transformer to 2,000 ohms (which makes the normal loss about 1.3 db.) the loss for low output levels of signals of about 1,300 cycles/sec. is about 0.7 db. The loss in stability-margin at this frequency is now only about 0.6 db. The sensitivity of the echo-suppressor is reduced by approximately 4 db., which loss can be regained by using a valve type 4022A or a valve with a similar mutual conductance of approximately 2.0 in the output stage of the repeater in place of the normal repeater valve having a mutual conductance of 1.3.

Construction and Maintenance of the Echo-Suppressor.

The whole of the equipment can be mounted on one side of a panel 7″ × 19″. The attenuation networks, including the transformers used to isolate the anode potential points in the attenuation networks from the line equipment, are inserted in the repeater circuit immediately prior to the repeater input terminals. The anode battery supplies to the final-stage repeater valves are broken and the bridge resistances inserted. The outputs of the repeater are connected to the signal rectifier circuits, and the grid-bias leads of the valves of the final stage are broken and the rectified signal-voltage is applied in series. All of these modifications can be made at the terminal blocks of the repeater and the echo-suppressor.

The maintenance required should be very small, and might normally consist of a three-monthly check of the balance of the two network currents by means of a differential-milliammeter, and if the currents have changed by more than 0.2 mA, to re-balance by adjusting the potentiometer-resistance in one of the anode circuits. A control current change of 0.2 mA is equal to a change in the difference of the valve-anode currents of about 0.5 mA. Measurements of the anode currents of three repeaters (using valves type 4019A and operating continuously night and day) made over a period of nine months, showed maximum changes in the difference of the valve anode currents of 0.5, 0.3 and 0.3 mA respectively.

There is no valve maintenance and the saving in valve supplies and valve replacements should be considerable. At the same time it should be pointed out that the increased anode current taken by one of the repeater valves when the suppressor is in operation may slightly shorten its useful life.

Prevention of Echo-Suppressor Operation on 600 *cycles/sec. and* 750 *cycles/sec. Signals used in a 2-Frequency Signalling System.*

In a 2-frequency signalling system where two different frequency-signals may be transmitted simultaneously in opposite directions no operation of the suppressor when these signals are transmitted may occur. This is partially prevented by connecting series resonant circuits, tuned to the signal frequencies of 600 cycles/sec. and 750 cycles/sec., across the input transformers to the signal rectifier circuits. The tuning inductances are 1/4 voltage ratio step-up transformers. The signal voltages obtained across the secondary windings are connected so that for frequencies remote from the resonant frequencies, they are in opposition and the nett rectified voltage across condenser C5 is very small, except at frequencies near 600 cycles/sec. and 750 cycles/sec., when the rectified voltages across condensers C2 and C5 in the grid circuits of the opposite repeater valves are approximately equal. Thus, signals of frequencies of 600 cycles/sec. and 750 cycles/sec. tend to increase the anode currents of both valves and so the bridge circuit from which the control current is derived is not unbalanced and hence no operation of the suppressor occurs. The repeater valve carrying the signal has an A.C. voltage applied to its grid and this prevents any decrease in its grid-bias voltage above that value which causes grid current to flow when the " peaks " of the A.C. signal are superimposed. This limits the effectiveness of the method to signals of amplitudes at the repeater output of approximately 8 db. above 1 mW. The tuned rejector-circuits, however, are not critical and greater tolerances in their resonant frequencies are permissible. The sensitivity-frequency characteristic of the suppressor with the rejector-circuits is shown in Fig. **29** (curve B).

A Summary of the Performance Characteristics and other features of the Valveless Echo-Suppressor.

1. An interlocking device between " go " and " return " halves of the suppressor ensures that only one side can be operated at any instant.

2. Due to the interlocking feature it is suitable for use as an ordinary echo-suppressor in the middle of a 4-wire circuit, or as a 4-wire terminal-suppressor or as a 2-wire echo-suppressor. 4-wire terminal-suppressors reduce maintenance costs, and also facilitate V.F. telegraphy and carrier telephony on 4-wire circuits.

3. The margin against false operation and " fading " is increased by 4 to 6 db. as compared with a non-differential type of suppressor. A further margin as compared with the valve type using grid-suppression is obtained, as the absolute sensitivities of the two halves of the suppressor are not affected by the " tail " of the anode-current grid-voltage characteristic, and can be kept more nearly equal.

4. With the present repeater valves ($\mu = 7$, $R = 5{,}000$) 20 db. suppression is obtained with a signal voltage corresponding to a level of 17 db. below 1 mW at the repeater output. Under such conditions the load imposed on the repeater output gives a 2.5 db. loss.

The harmonic due to the rectifier branch circuit is about 37-40 db. below the fundamental.

5. No modifications to the existing associated repeater apparatus are required, and the anode-current alarm relays can be retained since the valve-anode currents are never reduced below their normal value.

6. A saturation effect is inherent in the circuit to

prevent excessive " hangover " time due to strong signals.

7. The signal distortion introduced by the echo-suppressor equipment is less than that normally introduced by the associated repeater.

8. The capital cost of the echo-suppressor is very much less than that of the existing suppressors and no close specification is required for any component.

Maintenance costs should be very small and an additional saving on account of valve replacements and valve current will be made.

The use of Additional Amplifier Valves to increase Sensitivity, etc.

If it is considered desirable an additional single-stage amplifier can be inserted between the repeater output and the signal-rectifier circuit. The shunt-load across the repeater output can then be reduced to a negligible amount, whilst the auxiliary amplifier valves can be used in the D.C. bridge circuit in place of the existing repeater valves. No alterations to the valve circuit of the repeater need then be made, and the repeater characteristics, *e.g.*, output power, harmonic distortion and cross-talk are unaffected by the echo-suppressor. An increase of up to 25 db. in the sensitivity of the suppressor could be obtained.

For general use on normal 2-wire and 4-wire circuits, however, the performance of the valveless echo-suppressor is considered satisfactory.

Stabilized Amplifier-Circuits incorporating Variable-Attenuation Networks.

If the amplification in the two paths of a 2-way circuit is increased above a certain value coupling round the ends of the circuit will cause instability and an oscillation will be set up around the circuit. This effect normally limits the amplification that it is possible to obtain. Some important types of circuit which are affected by this limitation are :—

(1) Two-wire repeater circuits in which the out-of-balance circulating currents through the repeater differential transformers limit the repeater amplification and so prevent circuits with overall zero attenuation from being obtained.

(2) Radio terminals in a long distance transmission system, which operate effectively as 2-wire repeaters.

(3) High-attenuation submarine cables equipped with terminal amplifiers, each terminal amplifier being equivalent to a large amplification 2-wire repeater.

(4) Loud-speaker telephone equipment for subscribers' use incorporating a sensitive microphone and a loud-speaker. Coupling between the microphone and speaker circuits occurs (*a*) electrically, where these circuits are connected to the subscriber's line and (*b*) acoustically between the speaker and the microphone.

The problems involved in obtaining satisfactory operation of all these circuits are therefore very similar, and the general method of obtaining high-gain stabilised circuits incorporating rectifier-attenuation networks is as follows :—

Fig. **31** shows a 2-way circuit having amplifiers in the " go " and " return " paths and the two paths are coupled together by the differential transformers (or acoustic paths) 5, 6. Self-oscillation of the system is prevented by the attenuation network 2 and 3 in the main signal path, and which, in the quiescent state, are of high attenuation. Other attenuation networks 1 and 4, normally of low attenuation, are associated with the auxiliary signal paths, and the signals from these paths are used to modify the control currents through the networks 1, 2, 3 and 4.

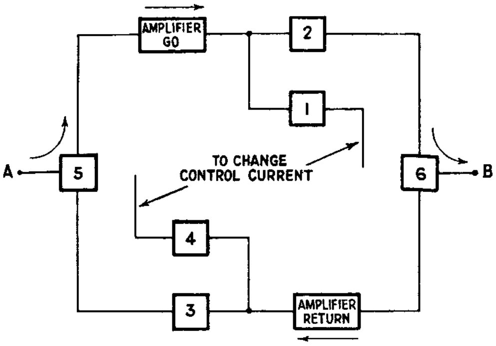


FIG. **31**.—SIMPLE STABILISED 2-WAY CIRCUIT. (SCHEMATIC).

A signal incoming to the circuit at A passes *via* the " go " amplifier through the network 1 (low attenuation) to change the network control current. This change results in networks 3 and 4 becoming of high (or higher) attenuation, and networks 1 and 2 becoming of very low attenuation, so that the signal from A can pass out to B. Simultaneously a signal will be transmitted *via* the differential transformer (or acoustic coupling path) 6 to the " return " amplifier, but will then be stopped by the high-attenuation networks 3 and 4. It is important that the increase in attenuation of network 3 should occur before the corresponding decrease in the attenuation of network 2 takes place, otherwise instability will occur. When the signal from A ceases the control current will restore to normal so that the network 4 becomes of low attenuation again. A signal from B can now pass *via* network 4 to change the control current in the reverse direction and networks 1 and 2 become of high attenuation, and networks 3 and 4 become of very low attenuation. The signal from B will now pass out to A.

The signals applied through the auxiliary networks 1 or 4 must cause an instantaneous change in the control current and thereby reduce the attenuation of the networks 2 or 3 so quickly that no clipping of the signal that passes to B can be detected. At the same time, in order to cover the pauses between words and syllables, the control current must not restore to normal immediately the signal ceases, but must persist or " hangover " for a period, preferably of about 1 second.

Derivation of the D.C. Control Current.

When an A.C. signal is passed to, say the " go " amplifier, the D.C. voltage obtained by rectifying a portion of this signal is applied to the grid of one of the valves in the " return " amplifier to decrease the normal negative grid-kathode potential and so increase the valve-anode current. The difference in the anode-currents of correspondingly controlled valves in the two amplifier circuits forms the network attenuation control current. The arrangement is shown schematically in Fig. **32**. It is assumed that the attenuation networks 1 to 4 have small attenuations when the control current flows in the direction of the arrow head, and a large attenuation when it flows in the reverse direction.

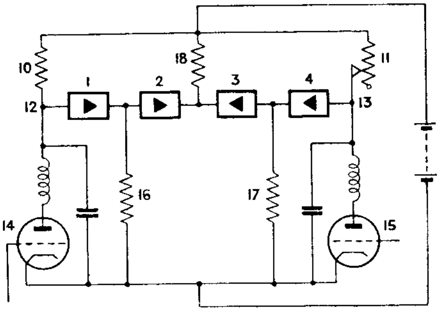


FIG. **32**.—CONTROL CURRENT BRIDGE CIRCUIT FOR STABILISED 2-WAY AMPLIFIER.

The resistances 10, 11 are adjusted so that points 12, 13 are at equal potentials when the grid-bias voltages of valves 14, 15 are normal, such as occurs in the quiescent state. Resistances 16, 17 and 18 ensure that the normal control currents through the networks 1 and 4 make the attenuations small, whilst the direction of the control currents through networks 2 and 3 is such as to produce a large attenuation. If the negative grid-bias voltage of the valve 15 is reduced, the potential of point 13 falls, due to the increased anode-current through resistance 11, and the main D.C. control current flows from point 12 to point 13, and the attenuation of networks 1 and 2 become small and those of networks 3 and 4 large.

The values of the resistances 16, 17 and 18 are selected so that the increase of attenuation of network 4 occurs before the corresponding decrease in the attenuation of network 2.

As the system has been described so far it is possible for a signal from A to take control of the circuit so that no return signal from B can be received. Since the level of the signal from A that is required to operate the control current circuit may vary very considerably and at times may be very small, unwanted changes of the control currents by extraneous signals, *e.g.*, line noise, room noise, will occur at times if the sensitivity is adequate for all normal use, and so speech signals in the reverse direction are locked out. This undesirable effect has hitherto been a serious drawback to the successful operation of any stabilised two-way amplifier system and has prevented any form of stabilised amplifier from being brought into general commercial use. This disadvantage has now been overcome by the use of a " break-in " device, enabling signals from either end of the circuits to " break in " and pass through the amplifier even if other signals in the reverse direction are normally present.

The Principles of the " Break-in " Device applied to Stabilised Circuits.

In Fig. **31** the signals used to change the control currents which flow through attenuation networks 1 and 4 operate by charging a condenser (after suitable rectification) in the grid circuit of a thermionic valve, thereby changing the steady anode current. To operate the " break-in " feature the condenser C is discharged by the " break-in " current. This is shown diagrammatically in Fig. **33**. As previously, signals from end A pass *via* the " go " amplifier and the network 1 to change the control current by charging a condenser at 7. The networks 3 and 4 are then of high attenuation, whilst the signal from A passes through network 2 to B. Signals from B now pass through the return amplifier *via* path 8 to supply a discharge current to condenser C at 7. Thus if the signal from A ceases, the discharge time of the condenser C at 7 is accelerated by the discharge current *via* path 8 so that the reply from B can operate the switching system *via* the attenuation network 4 immediately. This enables the signal from B to break in during the interval between words, which is normally covered by the hangover period of the condenser at 7. If the signal from A, however, does not cease, the signal from B can still " break-in " if it is large enough to supply a discharge current, *via* path 8, greater than the corresponding charging current *via* network 1. When these conditions apply in practice, the unbalance or echo currents of signals A *via* the differential transformer 6 (or the corresponding acoustic path) to the " return " amplifier will be sufficient to discharge the condenser C at 7 and so cause " clipping " in the speech transmitted from A to B. To avoid this a path 9 is provided so that signals from A *via* transformer 6 and path 8 are prevented by corresponding simultaneous signals *via* path 9 from discharging the condenser C at 7. The magnitudes and the effects of the signals in the paths 8 and 9 are proportional. Thus if there is a large out-of-balance signal in path 8 it will be opposed by a correspondingly large signal in path 9. A signal from B will add to the out-of-balance signal from A and if it is sufficiently large

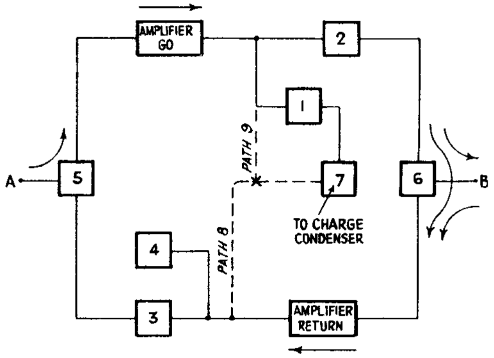


FIG. **33**.—STABILISED 2-WAY CIRCUIT WITH "2BREAK-IN " DEVICE. (SCHEMATIC).

will overcome the effect of the signal in path 9 and discharge the condenser C at 7. In a similar manner (not shown in Fig. **33**) signals from A can be made to " break-in " and pass to B before signals from A have ceased.

Circuit Arrangements showing the Method of Application of the " Break-in " Principle to the Stabiliser Circuit.

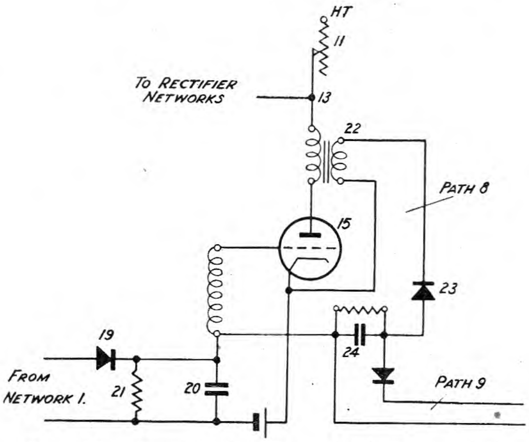


Fig. **34**.—Charge and Discharne Circuits of Condenser in Valve Grid Circuit.

The arrangements used to charge and discharge the condensers in the grid-circuits of the valves in the D.C. bridge providing the control current are shown in Fig. **34**. The main operating signal from network 1 (Fig. **33**) passes *via* rectifier 19 and charges the condenser 20 so that the grid-potential of the valve 15 (corresponding to the like numbered valve in Fig. **32**), becomes less negative with respect of the potential of its kathode. Condenser 24 can normally discharge through resistance 21 and the backward impedance of rectifier 19 in approximately 1 second. The " break-in " signal *via* path 8 (Fig. **33**) is derived from a winding (22 in Fig. **34**) of the output transformer of the " return " amplifier, and passes through the rectifier 23, and the resultant direct current discharges the condenser 20. The signal in path 9 (Fig. **34**) is also rectified and used to charge a condenser 24 in series with the rectifier 23. The voltage developed across the condenser 24 biases the rectifier 23, thereby preventing it from rectifying the signal in path 8, if the latter signal is due to " echo " or out-of-balance signals derived from the " go " amplifier. The discharge time of the condenser 24 is very short and need only be slightly greater than the " echo " time, from the " go " to the " return " amplifiers, so that the voltage across condenser 24 preventing rectifier 23 operating will follow the fluctuations of the signal level in the " go " amplifier. Any reply signal from B (Fig. **33**) applied to rectifier 23 not only adds to the echo signal already received, but will occur during the periods between words and syllables of the speech from end A, in which periods there will be little or no voltage across the condenser 24, so that the rectifier 23 will become operative and the condenser 20 will be rapidly discharged, and " break-in " will occur.

Applications of the Voice-Operated " Break-in " Switching System.

This method of voice-operated switching has been successfully applied to solve the problems of the loud-speaker telephone for use on normal telephone circuits, and whilst such an instrument may not directly come under the scope of the title of this paper, it has been shown that many of the problems involved are such as are met with in the more usual forms of telephone transmission systems.

The Loud-Speaker Telephone.

The loud-speaker telephone consists essentially of a small moving-coil microphone and a loud-speaker mounted side by side in a small cabinet to stand on the subscriber's table so that he can listen and speak to any other subscriber in the same manner as he would if that subscriber were sitting where the instrument is placed. A compact instrument has been developed occupying very little more table room than the ordinary telephone. (See Fig. **35**). A control is provided for adjusting the incoming speaker's volume and a key for connecting to the line or switching over to the normal telephone. This key is also provided with a non-locking position in which the microphone is short-circuited so that the subscriber can be in contact with a distant subscriber and yet not be overheard by that subscriber if he does not wish to be.

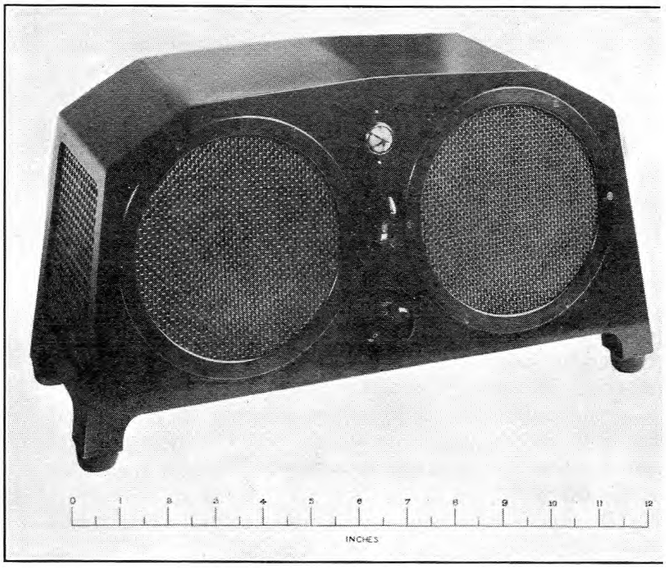


Fig. **35**.

The amplifier and voice-operated switching equipment, including the power unit, is mounted in a metal case approximately 20″ × 14″ × 12″, which may be installed remote from the table instrument if desired. The power consumption of 100w is derived from the A.C. supply mains (or *via* a motor converter if D.C. mains only are available).

The Amplifier and Voice-Operated Switching Equipment.

This is shown schematically in Fig. **36**. Corresponding parts of the system to those indicated in Figs. **32** to **34** are numbered similarly. The microphone and speaker amplifiers each contain two amplifying valves and one of these valves in each amplifier is used in the D.C. bridge circuit supplying the network control currents. The moving-coil transmitter 25 is connected to an amplifier 26, and a second amplifier 27 which uses the D.C. bridge valve 14. The microphone signal passes *via* the attenuation network 2 and the differential transformer 6 to line B. A nominal balance 28 of 800 ohms, is employed on the differential transformer.

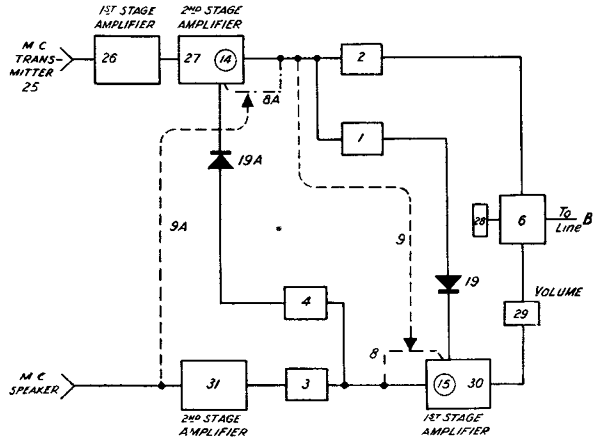


FIG. **36**.—LOUD-SPEAKER TELEPHONE. (SCHEMATIC).

In the speaker amplifier which follows an input volume control 29, the attenuation network 3 is connected in the circuit between the 1st and 2nd amplifier stages, 30 and 31, as the amplitude of the signal after amplifier 31 would be too great to be controlled by the steady current which passes through the attenuation networks and which is derived from the D.C. bridge circuit.

The voice-operated switching circuit from the microphone and " break-in " circuit from the line B are *via* attenuation network 1, rectifier 19 and paths 8 and 9. The similar circuits operating in the reverse direction are *via* attenuation network 4, rectifier 19A and paths 8A and 9A.

Circuit Details of the Loud-Speaker Telephone.

The complete circuit diagram is shown in Fig. **37**.

Determination of types of Valves and Anode-Supply Voltage required.

(*a*) *Output.*

The anode voltage must be sufficient, in association with the 2nd stage speaker amplifier valve, to supply adequate undistorted power to the loud-speaker even when the distant subscriber raises his voice.

(*b*) *Control Current.*

To obtain adequate control currents through the attenuation networks the valves associated with the D.C. bridge circuits must have large anode currents. Thus low-impedance valves are desirable and an anode supply of about 250v. Using valves type PX25 ($Z = 1{,}350$ ohms) a control current change of about 12 mA can be obtained with a resistance in the bridge circuit of 3,000 ohms. If a balanced type of attenuation network (as in networks 2 and 3) is used the maximum speech signal current that can be handled by them is 4.2 mA, which is satisfactory.

(*c*) *Desirability of Directly Heated Valves.*

By using directly heated valves the apparatus need only be switched on when required, *i.e.*, when initiating or receiving a call. Using PX25 type valves, a delay of 2.5 seconds occurs before the apparatus is " live " after switching on, which is not considered to be excessive. It is hoped, however, to reduce this time in the near future. To avoid " mains hum " in the microphone amplifier, a D.C. supply must be used for heating the 1st stage amplifier valve, otherwise A.C. can be used for filament heating.

Types of Variable-Attenuation Networks used.

The attenuation networks 2 and 3 in the main signal path are balanced and of the same form as those used for the echo-suppressor (see Fig. **24**). The maximum attenuation is about 70 db.

The networks 1 and 4 in the control signal path are unbalanced and consist of two networks in series. Unbalanced networks are used in order to obtain a larger ratio of the steady control current to the signal current flowing through the networks. The signal currents applied to the networks 1 and 4 are considerably greater than the corresponding currents applied to the networks 2 and 3 owing to the large switching sensitivity that is required. The actual value of the signal current in the first network of 1 and 4 may exceed the control current and the effective attenuation of the network is not then obtained. A second network is therefore connected in series to ensure that adequate attenuation is obtained of any signal that passes the first network. It is most important that no appreciable signal should pass through either network 1 or 4 when it is in the attenuating condition, as the effect of such a signal will be to change the control current and still further reduce the attenuation of the network and so ultimately produce instability of operation.

The transformers associated with the networks 1 and 4 are inefficient at low frequencies and the effect of room and exchange line noises (which in general have a large low-frequency content) on the voice-operated switches is reduced.

The Attenuation Network-Control Currents.

The normal network-control currents in the quiescent state are determined by the resistances 16, 17, 18 (Fig. **32**). A symmetrical arrangement has been found most satisfactory in which resistances 16, 17 are equal, each being 0.25MΩ. With the resist-

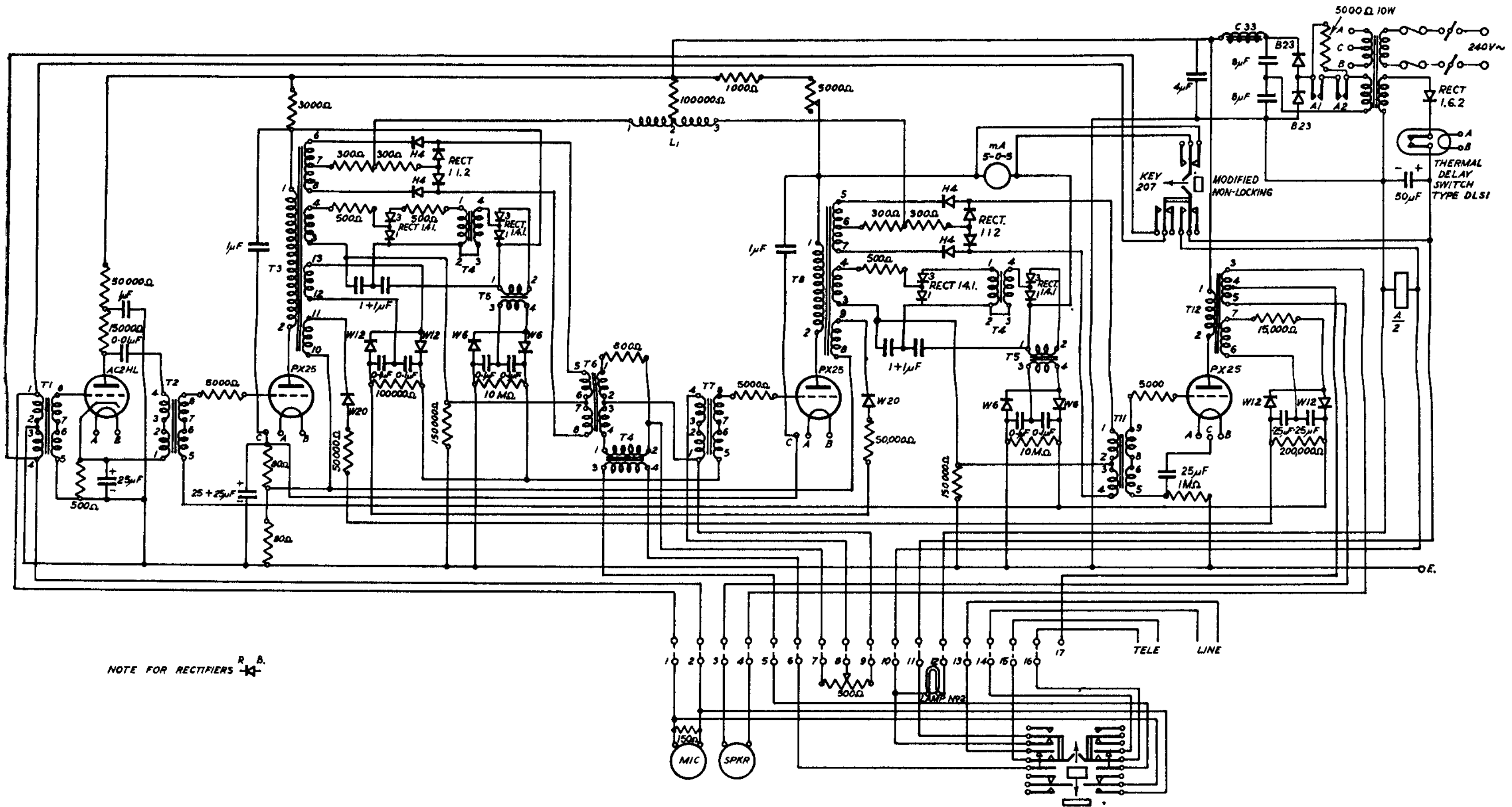


Fig. 37.—Circuit Diagram of Loud-Speaker Telephone.

ance 18, of 0.1MΩ, the network-control currents are as follows :—

Networks 1 and 4	...	0.5 mA (low attenuation).
,, 2 and 3	...	0.3 mA (high attenuation).

Under these conditions both the microphone and the speaker circuits are of high attenuation in the quiescent state, but each requires only a small charge of the control current to open up the network. In general this condition is most satisfactory, although the control current may be adjusted by varying resistance 11, so that either of the networks 2 or 3 is of low attenuation and either the microphone or the speaker is then connected to the line in the quiescent state.

Satisfactory operation of the switches occurs under all normal conditions of use provided the control currents do not vary more than ± 0.5 mA from the above values. This represents a change in the difference of the associated valve-anode currents of approximately 1.5 mA, which will only occur after long periods of use. From the results of tests on the valves, which show a remarkable degree of uniformity with regard to their anode currents under the conditions of use, it is unlikely that the control current will need to be adjusted more often than once a year. Provision is made in the apparatus, however, to enable the subscriber to re-adjust the control current if it changes. A control panel is incorporated containing a milliammeter, a non-locking key and a variable resistance. On depressing the key the milliammeter is connected in the control current circuit, the microphone is short-circuited, and current is switched on to the set. The variable resistance knob is then turned until the milliammeter deflection coincides with a red line, which represents the correct value of the control current in the attenuation networks.

Adjustment of the " Break-in " Facility.

The " break-in " facility derived *via* paths 8 and 8A (Fig. **36**) should be as large as possible and at the same time a reasonable margin against " break-in " by " echo " signals must be provided *via* paths 9 and 9A. Since the main echo signal from the speaker may be delayed by room conditions before entering the microphone, the hangover time of the " anti-echo " " break-in " path 9A should be about 30 milliseconds, compared with about 5 milliseconds for path 9. It is desirable to make the " break-in " facility from the line easier than that from the microphone for the following reasons :—

(*a*) The subscriber using the loud-speaker telephone can control the distant end subscriber's incoming volume and therefore his " break-in " facility.

(*b*) He knows at once whether he " breaks-in " on the distant end subscriber, and will automatically raise his speech level if he does not " break-in."

(*c*) If two loud-speaker telephones are connected together the subscriber who " breaks-in " *via* his microphone circuit, thereby cutting out the distant end subscriber, must always " break-in " at the distant end as well, otherwise both subscribers can talk simultaneously and neither will hear the other.

If it is desired to use the loud-speaker telephone in noisy situations, no alteration in the " break-in " facility as such is necessary, but a reduction of the microphone sensitivity, together with a corresponding increase in the speaker sensitivity by increasing the gain of the 2nd stage speaker amplifier 31 (Fig. **36**), will give improved operation. The reduced microphone sensitivity enables the distant-end subscriber to break through the room noise more easily, and because of the increased speaker-circuit amplification a louder signal, necessary if it is to be heard above the room noise, is obtained. The decreased microphone sensitivity is not a disadvantage as it is compensated for by the increased loudness of the signal into the microphone due to the subscriber raising his voice above the room noise. It has been found that a loud-speaker telephone gives more satisfactory operation in a noisy situation than an ordinary telephone not equipped with a transmitter cut-out switch, due to the side tone obtained on a normal telephone.

Amplifier Characteristics.

No attempt has been made to produce an amplifier with a uniform frequency-response characteristic over the complete speech-frequency range, *i.e.,* 50 to 8,000 cycles/sec., but rather, to obtain the largest amplification with a good frequency response up to 3,000 cycles/sec. The microphone amplifier is made insensitive at low frequencies as it has been found that room echo and reverberation are most marked at frequencies below 500 cycles/sec. and that a loss in articulation can occur due to these causes. Since the instrument is to be used in conjunction with normal telephone circuits which may have a limited uniform frequency-response characteristic of 300 to 2,500 cycles/sec., it is not considered desirable to produce an instrument capable of showing up the deficiencies of the telephone system, particularly if by so doing the cost of the apparatus is increased, and no material gain in articulation efficiency is produced.

Microphone Loud-Speaker.

A moving-coil microphone which has uniform frequency response characteristic from 50 to 6,400 cycles-sec. has recently been developed and this instrument forms a very satisfactory transmitter and receiver for the loud-speaker telephone. The microphone is set back in the cabinet so that there is free access for sound to pass round to the back of the instrument, whilst the speaker is mounted on the front of the cabinet to obtain the maximum baffle effect at low frequencies.

Arrangement of the Volume Control.

The volume control affects the incoming signals only. If the volume control were in the form of a variable attenuator in the line both incoming and outgoing signals would be affected. Thus, if two loud-speaker telephones were connected together, there would be two independent volume controls in each signal circuit, so that neither subscriber would have complete control of either signal.

The Performance Characteristics of the Loud-Speaker Telephone.

The following performance characteristics were obtained on an experimental set some time ago. Various improvements have since been made so that the actual performance characteristics are in many cases better than the figures quoted.

(a) Receiving Volume.

The received volume when listening two feet away from the combined speaker-transmitter can always be adjusted to be up to 10 db. above that received on a hand microtelephone (No. 162) held close to the ear, with a maximum power output from the speaker amplifier of 1.5 watts.

(b) Transmitted Volume to Line.

Whilst the volume efficiency when spoken into at a distance of two feet is 8 db. below that of the standard transmitter (No. 162) spoken into with the same speech level, the actual signal volume to line under working conditions is at least equal to that obtained when a subscriber uses a telephone (No. 162). This is due to :—

(1) Complete absence of sidetone.
(2) The psychological effect of talking into a transmitter two feet away causes the speaker to raise his voice as compared with speaking directly into a telephone transmitter.

(c) Transmitter Articulation.

This is equal to that from a standard telephone (No. 162) when speaking with equal intensity (as in (*b*)) and listening on a standard telephone (No. 162) through a 25 db. junction under reference equivalent conditions.

This test was conducted in a moderately acoustically damped room, typical of a small office.

(d) Receiver Articulation.

The articulation obtained from a standard telephone transmitter (No. 162) when received on the loud-speaker is equal to that obtained when received on the receiver of a telephone (No. 162) with a 25 db. junction.

NOTE.—Tests (*c*) and (*d*) all gave articulation efficiencies of between 89% and 92%.

(e) Transmitter Reproduction.

Speech received on a telephone receiver from the transmitter is more natural than from a telephone (No. 162).

(f) Operating or Switching Sensitivity of the Transmitter.

Slow speech spoken at a level 20 db. below reference volume (S.F.E.R.T.) will hold the transmitter circuit through so that the listener at the distant end cannot detect any " clipping " or " fading."

(g) Operating or Switching Sensitivity of the Receiver.

Standard reference volume speech into a transmitter (No. 162) under reference equivalent conditions will hold the speaker circuit through with a junction loss of 52 to 55 db.

NOTE.—The normal control current in the quiescent state is the same as for condition (*f*). The relative sensitivities of the transmitter and receiver can be changed, one increased and the other decreased, by changing the normal value of the control current in the quiescent state.

(h) " Breaking-in " Facility.

With reference-volume continuous speech applied to the transmitter at a distance of 2 ft. speech from the distant end subscriber at reference-volume into a telephone transmitter type 162 under reference-equivalent conditions will break through, and come out to the speaker, with a junction loss up to 27 db. (Z_0 = 600 ohms).

When the level of the disturbing speech to the transmitter is raised approximately 10 db., which is excessively loud, a junction loss of 22 db. is permissible.

If longer junctions are in use the facility for " breaking-in " is reduced, that is, the distant-end subscriber will either have to increase his speech volume (which is normally done in order to " break-in ") or else wait until a pause occurs in the conversation, or until the level of the speech incoming to the transmitter falls below reference volume.

The operating times of the voice-controlled switching devices are so small as to be inappreciable to the ear.

Some Uses of the Loud-Speaker Telephone.

Apart from the general use of the loud-speaker telephone by any subscriber who makes continual use of the telephone and is in a position to pay for the service—and this will include most business executives commanding a salary of £1,000 per annum and over—it should have a considerable field of use :—

(1) As a means of creating an impression (either real or imaginary) of power associated with the user, and thereby maintaining his prestige.

(2) In connection with control systems where instructions are normally passed by telephone, *e.g.*,

(*a*) Railway signalling.
(*b*) Engine-room control on ships.
(*c*) Power-station control.

(3) For superimposed telephone systems on high-voltage power lines.

Since the equipment can be placed at a distance from the user with a guard between, the difficulties of isolating the telephone from the associated high-voltage transmission circuit are very considerably reduced.

(4) As standard equipment in luxury suites in hotels and transoceanic liners.

Conference Facilities provided by a Modified Loud-Speaker Telephone.

A conference between two groups of people at different centres can be conducted with loud-speaker telephones at each end. If the groups exceed three or four persons then it is preferable to replace the combined table instrument by a separate non-directional microphone unit and loud-speaker unit. The microphone unit consists of two microphones, similar to those used in the table model and mounted with their axes horizontal, but at right angles to each other. The speaker unit consists of three instruments—similar to the microphone, mounted one on each side of an inverted tetrahedron, which is suspended above the centre of the conference table. The microphone unit can be suspended—or placed on the table—below the speaker unit, or alternatively two or more units connected together be placed at different parts of the table. The latter arrangement is preferable if a large table is used.

Switching Arrangements.

Since, in general, there will be one main centre where the Chairman sits and one or more smaller local centres it is best to so adjust the switching control currents that the main-centre microphone is connected through to the local centres in the quiescent state. The local centres will then hear all that takes place at the main centre, and if they wish to be heard will have to speak up slightly. Since the microphones and the loud-speaker are separated by a greater distance than with the normal loud-speaker telephone set and the acoustic coupling between them is less, a larger output level from the loud-speaker and an increased microphone sensitivity can be used, without the signal from the loud-speaker itself " breaking-in " *via* the microphone circuit and so causing " clipping " of the speech.

Operational Difficulties.

One of the difficulties of a loud-speaker conference telephone system is that any one centre—and particularly the main centre—forgets, during the discussions, that another body of people who cannot be seen is also trying to listen to what they are saying. Discussions at conferences often develop into subdued murmurings and lip reading is needed—which the microphone does not supply at present—in order to understand the speakers. Provided, however, that the Chairman exerts proper control, then conferences can be conducted very satisfactorily by these means.

2-Wire Circuits Incorporating Voice-Operated Stabilised Repeaters.

Experiments are now being made on repeatered circuits with a view to replacing 4-wire by 2-wire circuits, equipped with one or more stabilised repeaters, so that zero-loss circuits can still be obtained, and whilst these tests are as yet incomplete, it is thought that brief details of the scheme may be of interest, as a very considerable saving will be made in the cost of zero-attenuation circuits, when the scheme is brought into operation.

Fig. **38** shows schematically a stabilised form of 2-wire repeater incorporating rectifier-attenuation networks. The main attenuation networks N2, N3 in the signal circuit precede the repeater as in the case of the echo-suppressor. Two-stage auxiliary amplifiers A.A.1, A.A.2, are used to amplify the speech signals required to vary the network control currents, and networks N1 and N4 are inserted in the output circuits of these amplifiers. The 2nd stage auxiliary amplifier valves are also used in the control-current bridge circuit, so that the main repeater valve circuit is not modified and the maximum output of the repeater valves is available to give the high output levels desirable in the stabilised repeater. The " break-in " paths 8 and 8A, and the paths 9 and 9A to prevent " echo " signals from breaking-in operate in the same manner as for the loud-speaker telephone.

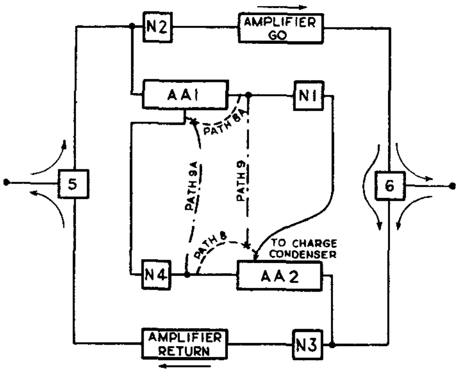


FIG. 38.—2-WIRE VOICE OPERATED STABILISED REPEATER. (SCHEMATIC).

The Level Diagram of a 2-wire Stabilised Repeater Circuit.

Fig. **39** shows the proposed level diagram of a London-Liverpool circuit with normal 2-wire repeaters at London, Fenny Stratford and Liverpool, and with a stabilised repeater at Birmingham, approximately in the middle of the circuit. The amplifications of the repeaters at London, Fenny Stratford and Liverpool are made as small as possible in order to increase the stability margin of the two parts of the circuit each side of the stabilised repeater. The presence of a stabilised repeater in the centre of the circuit rather than near one end should enable a larger stability margin to be obtained.

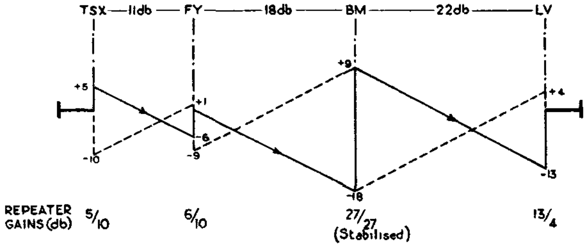


FIG. 39.—TYPICAL PROPOSED 2-WIRE STABILISED REPEATER CIRCUIT.

SOME NOTES ON THE DISCUSSION.

CAPT. A. C. TIMMIS :

Of all the devices described in the paper, the one which impressed me most with its beautiful ingenuity is the " break-in " device of the stabiliser.

To anyone who has attempted to make a device of this sort operate when wanted and not be held up by extraneous noises, the successful completion of the " break-in " device is really quite an epoch-making thing. The other application is less spectacular, but I think more economically important—the one which makes possible a stabiliser. It has long been one of our desires to reduce the overall loss of a 2-wire circuit to zero, but it has been impossible, partly on account of line noise, until Dr. Ryall's " break-in " device came along, which seems to be quite impervious to line and room noise, and is about to be employed on a demonstration circuit. The economic advantage is that we can get on two wires almost as much as we got on four.

It is worth mentioning that there are other application than those which the author has described for the cupreous oxide rectifier. It is really a non-linear resistance. There is a close analogy between the grid-bias of a valve which controls the internal impedance, and the direct current which controls the internal impedance of the metal rectifier. There are several applications, and a very important one is to replace valves as modulators and de-modulators in carrier systems.

As regard the heterodyne oscillator, I think Dr. Ryall would be the first to agree that the credit for the extreme accuracy and stability should go to Messrs. Sullivans, who produced the high frequency oscillators together with the special coils and condensers. But the equally creditable constancy of output is entirely due to Dr. Ryall. Since the original het-oscillator was described in 1926, various administrations and companies have taken up the idea but no one has produced a heterodyne oscillator for commercial application with anything approaching the accuracy and stability of the Ryall-Sullivan oscillator.

DR. G. W. SUTTON (*Siemens Bros., Ltd.*) :

There appears to be two lines of approach to the design of the logarithmic output meters described by Dr. Ryall. One is to modify the electrical rectifier and use a linear current measuring device; the other is to use a linear rectifier and modify the current meter. The latter has certain advantages of simplicity and freedom from frequency errors. I have used for some time a meter with a tapered gap which gives an approximation, though not so close as I should have liked, to a logarithmic response. A better line of attack has been mentioned in a German paper, where the usual spiral control spring of the meter was replaced by one which wraps itself round the edge of a small cam and so provides an increase of control torque with increasing deflection. This could hardly be improved on for simplicity, and its construction should not prove difficult to a skilled instrument maker.

Turning to an entirely different subject—not a difficult matter in a paper covering so much ground—Dr. Ryall claims "complete absence of side-tone" for his loud-speaker equipment. This may be true of the apparatus considered alone; but considered in conjunction with the speaker it is certainly not true. Actually the speaker is subject to the natural side-tone arising from the air-path between his mouth and ears. In contrast with this, some anti-side-tone telephones, on certain connections, give a level of side-tone which is appreciably lower than this. In fact it is a feature of badly designed anti-side-tone circuits that they give something approaching " complete absence of side-tone " on some line connections—a distinctly undesirable feature.

MR. G. J. S. LITTLE :

It has been a great pleasure to have witnessed Dr. Ryall's demonstrations of many of the novel circuits described in the paper. An outstanding feature is the important part played by dry plate rectifiers. Rectifiers are being increasingly used and a simplified mathematical description of their characteristics is badly needed. It seems likely that there are fundamental characteristics, whereby the performance of a rectifier can be described, of a similar nature to internal impedance and amplification factor in the case of valves. A treatment of the performance of rectifiers on these lines seems possible.

As one who is concerned in bringing new developments in transmission into service I feel impelled to remark upon the fundamental difference between the two sections of Dr. Ryall's paper. The performances which have been quoted for heterodyne oscillator and other measuring equipment can be demonstrated as matters beyond dispute by laboratory measurements. In the case, however, of the voice-operated devices described in the second part of the paper the results obtained under practical conditions in terms of speech quality cannot be so accurately assessed and I am of the opinion that the enthusiasm of the research worker may have led the author into over-statements in some cases. To take a particular instance. The sensitivity of the valveless echo-suppressor which has been described is considerably less than that of the valve-type echo-suppressors at present in use, but it is stated that the sensitivity of the valveless-suppressor has been shown to be adequate for all zero-circuits. The question of the amount of allowable echo is to some extent a matter of opinion, and although I have little doubt the new type will be found to be satisfactory, I do not think the statement can be substantiated on the result of the comparatively few trials which have so far been possible.

MR. H. A. G. HOUSE (*S.T. and C., Ltd.*) :

I am most interested in the first part of the paper dealing with transmission measuring apparatus, and here Dr. Ryall has certainly given a great deal of most valuable information and a great deal of food for thought. There are one or two points in the paper on which I should like some information. Mention is made of the possibility of making the attenuation-frequency measurements of a circuit entirely automatic, but doubt is expressed as to whether such automatic recording has many advantages over the manual method. I should very much like to know what has led him to that conclusion. I believe that various European Administrations are very interested in this subject, and the German Reichspost is actually operating a number of automatic recording equipments. It seems to me that in the method he describes, where the measurement of the characteristic is made manually, the noting down of frequencies, etc., takes quite a considerable time, depending on the number of frequencies the measurements are taken at, whereas with the automatic recorder, once the recorder is set up, a large number of circuits can be run through and a record taken automatically and rapidly. You have thus a permanent record of the circuit condition. If on the other hand only a visual check is made of the circuit condition, by watching the direct reading meter of the level measuring set, the automatic sweep over the frequency range eliminates the personal element on sweeping speed. The automatic method may also have considerable advantages on International circuits, where language difficulties might arise on the manual method.

In connection with the direct reading transmission measuring sets, I notice that Dr. Ryall has developed his logarithmic meter scale by circuit design as opposed to the method of shaping the poles and core of the receiving meter. I should very much like his views as to the relative advantages of these two methods of achieving an open decibel meter scale. I believe I am right in saying that change of scale shape, due to change in frequency, is reduced if the pole shaping method is adopted.

In the description of the direct-reading attenuation measuring set, he stated that this set can be used for accurate level measurements at all audio and music frequencies. A little further on he stated that the amplifier portion of the set is compensated for frequency errors between 30 and 8,000 cycles. He gives figures for errors at higher frequencies running up to 40,000 cycles, but I am not clear as to whether these apply only to the amplifier portion or the whole measuring set.

As a last remark, I should be very interested if he would give the overall frequency range of the set for measuring accuracies of 0.2 and 0.5 db.

Mr. D. McMillan.

I was particularly interested in the description of two forms of attenuation networks, in which the impedance elements consist of dry-plate rectifiers. One is naturally led to enquire immediately as to the linearity of such a network. Will it introduce harmonics? Some measurements have recently been made, showing the amount of harmonics which such devices do introduce.

Figs. **40** (*a*) and (*b*), show the performance of three types of variable-attenuation networks.

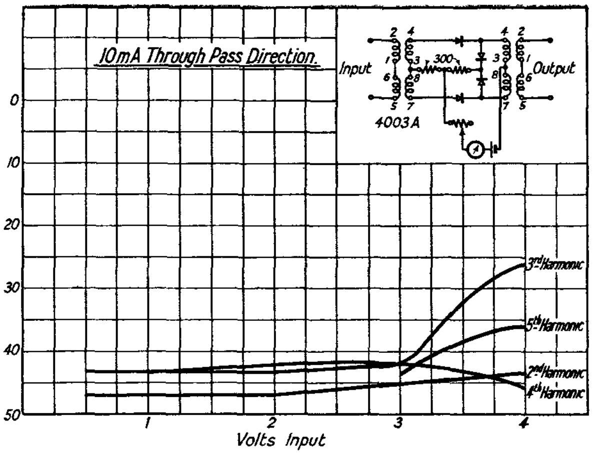


Fig. 40(*a*).

Fig. (*a*) refers to a type of attenuator which has been described in the paper. It will be seen that the harmonics introduced when a pure sinusoidal voltage is applied to the network are about 45 db. below the fundamental for all input voltages up to about 3 volts. The 3rd and 5th harmonics rise rapidly in value as the input voltage is increased from this figure.

Fig. (*b*) refers to a different type of attenuation network. As may be seen from the circuit diagram the network consists essentially of a hybrid transformer which is normally balanced by the two similar impedance networks A and B. The passage of a direct current through B (as indicated on the diagram) destroys the balance of the transformer with the result that the attenuation between the input and the output of the transformer is reduced.

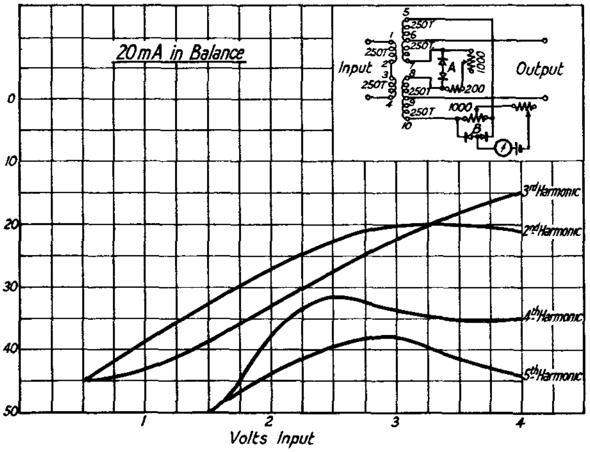


Fig. 40(*b*).

The harmonics introduced by this form of attenuator increase progressively as the input voltage is increased. It will be observed that it introduces less harmonic than does the type of network shown in Fig. (*a*), for input voltage of less than 0.5 volt.

Fig. (*c*) shows the circuit of a network which I believe to be of a new type. The attenuation is a maximum when current is flowing through the control path. With 20 mA. of direct current flowing as shown on the diagram the attenuation through the network is of the order of 60 db. and this figure does not alter for a change of ± 25% in the control current.

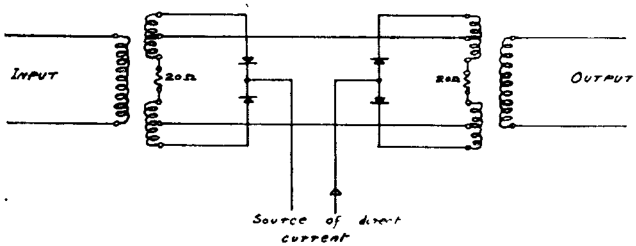


FIG. **40**(*c*).

When transmitting with minimum attenuation (no controlling direct current flowing) this network introduces no measurable harmonics even when the input voltage is as high at 10 volts.

MR. C. A. BEER :

Dr. Ryall's paper gives a clear indication of the technique involved in precision methods as applied to the setting up and maintenance of present-day trunk lines. The growth in the number of circuits and the increase of circuit efficiency has made testing more important while speed and accuracy are very important factors.

Speaking as one who has used the newer equipment, I can testify to the considerable advantage of this as compared with the older types. On the other hand, it is becoming evident that in trying to speed up things the personal factor can play a noticeable part. The speaking difficulties between two towns, and the obtaining of intermediate repeater stations involve a considerable proportion of the total time taken. Perhaps therefore, Dr. Ryall could give us an idea as to whether he thinks the automatic recording device should be brought into service sooner or later.

Dealing with possible variations in amplification, —mainly in the measuring set—these are introduced by fluctuations in the supply voltages and the precision of the measurement may thereby be materially influenced. In this connection it may be noted that the major variations on trunk lines in this Country are due to the effect of H.T. voltage. Some form of automatic control of the battery supplies may be desirable.

The impedance of Dr. Ryall's heterodyne set is very close to 600 ohms and thereby correct conditions are simulated. Instead of rather wasteful higher power valves, low power, long-life valves, have been employed with advantage. It would be interesting to know whether the impedance of the milliwatt oscillator is maintained at a value of 600 ohms.

Touching on the problem of 2-wire repeaters, we have had experiments on the London-Liverpool route without a stabiliser, but with a suppressor, and it was found easy to produce a good 2-wire circuit of this length. The latter, is of the valveless type. The circuit is stable at 2 db. at 800 cycles and it rises to 5 db. at 2400 cycles per second.

Existing 4-wire circuits are stable at approximately 1.5 db. overall so that for the Liverpool route the 2-wire circuit is only .5 db. worse than the 4-wire circuit. For longer circuits, and, or, poorer cables however, the advantage of the 4-wire system will become considerable.

MAJOR F. E. A. MANNING :

With regard to the practical application of these instruments, we can picture an idea germinating in the author's mind, then being brought to some form of construction in the laboratory, and lastly to the manufacturer and commercial production. With the exception of the Ryall-Sullivan oscillator, there may still be " teething " trouble before the apparatus we have seen is put on a manufacturing basis. For instance, with regard to the transmission measuring set, there is no indication given to the operator that 1 milliwatt is actually leaving when he is " sending." Does Dr. Ryall think the operator has sufficient confidence in his set to dispense with this indication? Again, with regard to the battery voltages, we work the 130V battery with limits of ± 9V. The oscillator will stop oscillating if this voltage falls below 123 volts, and I should like to know whether there is any difficulty in increasing the range of anode-voltage. Again, when the apparatus goes into commercial production, there are small items which have to be changed. Will these oscillators and transmission measuring sets give as good a performance as the very carefully produced models we have seen tried at this meeting? Will the limits given in the paper be realised commercially?

The constant-frequency oscillator, certainly meets a very widely felt demand. Some seventy per cent. of repeater station time at control stations is taken in sending out 800 cycles, and in point of fact when actually sending out with the existing apparatus you cannot do anything else with the transmission measuring set, and associated oscillator.

In the case of the stabilised echo-suppressor, the trials are not as yet concluded, but I would like to ask Dr. Ryall if he is convinced that the terminal echo-suppressor justifies its existence, since it is necessary to use a full double stage four-wire-repeater at terminal stations? I think the economics require further study before existing apparatus is scrapped.

In the level diagram of the proposed 2-wire circuit, may I ask Dr. Ryall why he has gone outside the usual limits? The limits usually adhered to have very considerable justification, and have been agreed internationally. It seems doubtful whether we can superimpose on our existing cable network the levels mentioned without introducing cross-talk difficulties.

AUTHOR'S REPLY:

I agree with Captain Timmis that the remarkable accuracy and stability of frequency of the heterodyne oscillator is due to the close co-operation of Mr. W. H. F. Griffiths (of H. W. Sullivan, Ltd.) who designed the oscillatory circuit components to such a high standard of excellence. An article by Mr. Griffiths in *The Wireless Engineer* (May, 1934) describes more fully than in this paper the various factors influencing the oscillator frequency and how the accuracy has been obtained.

The fact that the oscillator failed to oscillate when the H.T. supply voltage dropped to 123 volts was due to the original design being based on a normal supply voltage of 150 volts. and a minimum supply voltage of 130 volts. An alteration in the anode and screen-grid supplies potentiometer to suit the lower H.T. voltages in use has now been made and oscillations do not cease until the voltage drops below 90 volts.

Dr. Sutton's suggestion that a logarithmic scale instrument can be obtained by shaping poles, or by using a spring wound on a cam is, I believe, only satisfactory over a small decibel range. In order to obtain a logarithmic scale with a 40 db. range the sensitivity at full scale must be only one per cent. of the sensitivity obtained with small scale deflections. I do not know of any means other than the variable shunt method that is capable of providing such a wide range of sensitivities. Since the shunt is in a D.C. portion of the circuit when it is used in the direct reading attenuation measuring set, the frequency of the applied signal has no effect on the scale shape and I must apologise to Mr. Howse for not having made it quite clear in the paper that the figures given for the accuracy of the set are for the set as a whole, and include both the amplifier and rectifier variations. The maximum error for readings between zero level and − 30 db. over the frequency range 30 p.p.s. to 10,000 p.p.s. is less than ± 0.2 db. It is, of course, essential that the supply voltages should remain constant and it is proposed to fit discharge-tube voltage stabilizers to both the heterodyne oscillator and measuring set H.T. supplies, or alternately to use a separate source of supply derived from a small motor generator set.

My remarks regarding the use of automatic recorders were intended to be in connection with the lining up and checking of existing circuits in this Country. For international circuits, which may be considerably longer and where language difficulties tend to slow up circuit testing; the use of automatic recording apparatus is probably more satisfactory.

Mr. Beer can rest assured that the impedance of the neon-tube-controlled one milliwatt oscillator is actually 600 ohms. Since the voltage across the neon-tube is unaffected by load conditions the impedance at this point of the circuit must be zero, so that the actual impedance at the output terminals is equal to the 600 ohms connected in series with the output transformer, plus the series impedance of the transformer, which is made very low. Actual bridge measurements of the output impedance at 800 p.p.s. show that it is within 0.5 per cent. of the correct value. The oscillator has now been given a three months' trial at the London Repeater Station and has been found entirely satisfactory and is considered a great asset in lining up circuits.

The rather extensive uses of the metal-oxide rectifier have only been made after careful consideration of their reliability in the manner in which they are intended to operate. Their reliability as rectifiers, in which they are required to have a relatively low forward resistance compared with a high backward resistance is now universally accepted, and it is this property of the rectifier that is required in the variable attenuation networks used in the echo-suppressor, loud speaker telephone and 2-wire stabilizer circuits. The actual shape of the current-voltage characteristics can change to a large degree before any serious change takes place in the attenuation characteristic of the rectifier unit.

The harmonic produced by the rectifier attenuation network as measured by Mr. McMillan cannot be considered large, but even so, it is considerably larger than would be obtained if the circuit impedance associated with the attenuation network were 5000 ohms instead of 600 ohms, as shown. The distortion obtained is due to the variable impedance of the rectifier elements in the series path. If the load has a higher impedance the resultant distortion is reduced, with an optimum load of approximately 5000 ohms. The capacity of the rectifier elements and the load of the shunt rectifiers limits the maximum impedance of the load.

Regarding the echo-suppressor, it would only be desirable to instal it at a terminal station if a full 2-way repeater was in use and if the accommodation permitted. The suppressor can be used equally as well in any intermediate repeater station, and, in view of the congestion that exists in the terminal stations, will probably be installed at the intermediate stations. Mr. Little doubts whether the sensitivity of the valveless suppressor is adequate, and whilst I agree that it may appear to be on the low side when quoted in terms of decibels suppression for a given level of input signal, the speedier operating time and the larger frequency range over which it is sensitive as compared with the existing valve suppressor need to be taken into account when comparing the actual sensitivity figures. The tests so far made—including the tests on 2-wire zero attenuation circuits fitted with the valveless echo-suppressor—do not indicate that the suppressor-sensitivity is inadequate. The 2-wire zero attenuation circuit fitted with an echo-suppressor is only possible where the highest quality cable is available, which enables good line balances to be obtained. The margin of stability obtained is small.

Further details of the operation of the 2-wire stabilised circuit are now available. An experimental London-Leeds 2-wire circuit having a 5.5 db. attenuation at 800 p.p.s., rising to 15 db. attenuation at 2000 p.p.s., and with a stability margin of 2 db. with both ends open-circuited has been converted to a zero loss circuit with an attenuation of less than 1 db. at 2200 p.p.s.

A schematic diagram showing the form of the stabilised repeater is given in Fig. **41**(*a*). No measurable articulation loss or distortion is introduced by the stabiliser. The level diagrams of the circuit before and after inserting the stabilised repeater, together with the overall frequency characteristics are shown in Figs. **41**(*b*)—(*e*). The repeater gains at Derby necessitate slightly higher output levels—in order to obtain a zero attenuation circuit —than are normally employed.

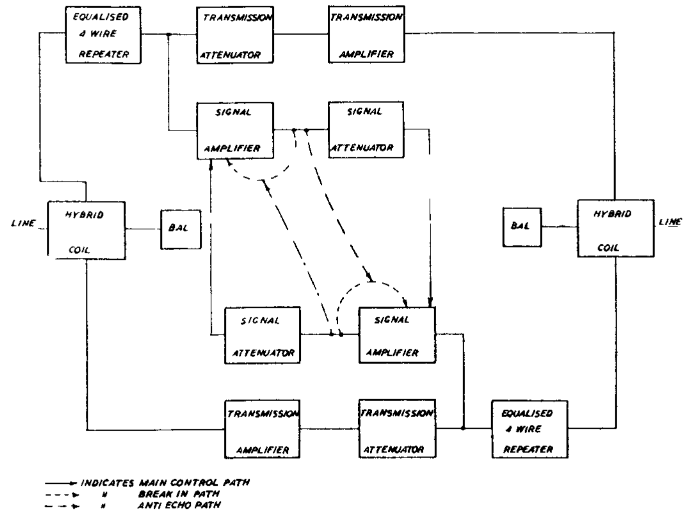


FIG. **41**(*a*).—SCHEMATIC OF V.O. SWITCHING OR STABILISED REPEATER.

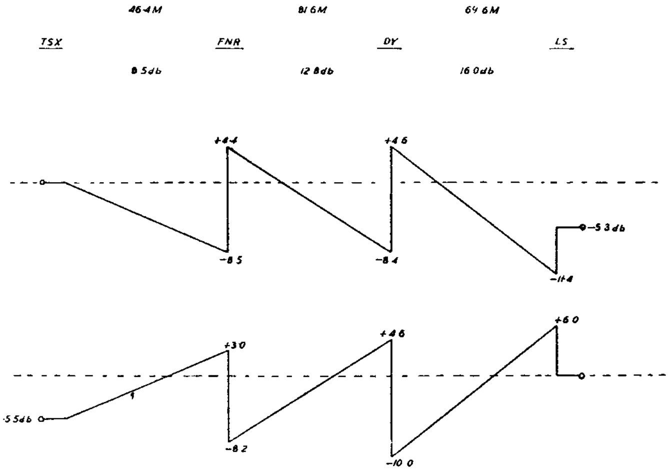


FIG. **41**(*b*).—LEVELS ON NORMAL 2-WIRE CIRCUIT TSX-LS44. CIRCUIT EQUIVALENT—5.5 DB.

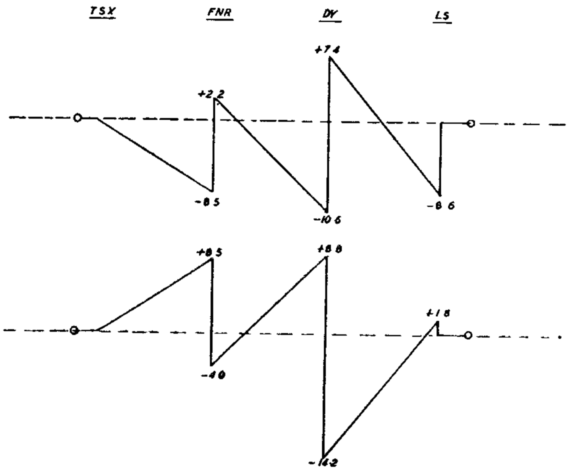


FIG. **41**(*c*).—LEVELS ON THE STABILISED 2-WIRE CIRCUIT TSX-LS44. CIRCUIT EQUIVALENT—0 DB.

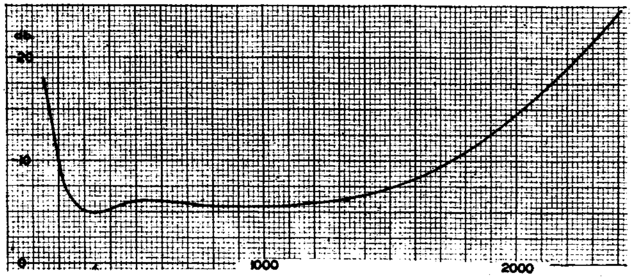


FIG. **41**(*d*).—NORMAL 2-WIRE CIRCUIT TSX-LS44. OVERALL ATTENUATION-FREQUENCY CHARACTERISTIC.

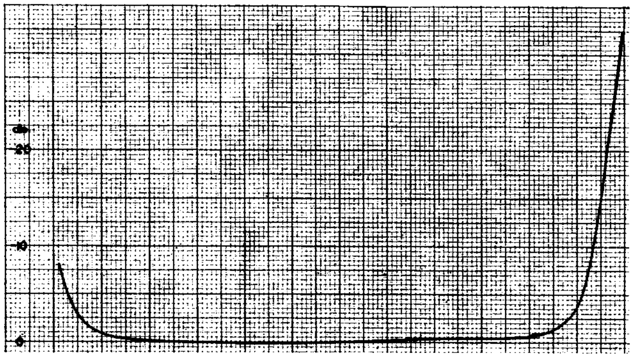


FIG. **41**(*e*).—STABILISED 2-WIRE CIRCUIT TSX-LS44. OVERALL

The stability margin of the London-Derby section with the London end open-circuited is 7 db., whilst the Leeds-Derby section has a stability margin of 6 db. with an open circuit at Leeds. These margins are adequate to prevent any traces of incipient instability that is present on many 2-wire circuits.

The stability margin at Derby is governed, not by oscillation, but by " clipping," of the speech due to echo currents " breaking-in " in the reverse direction. However, the gain at Derby can be increased 10 db. in each direction—making a + 10 db. circuit overall, and it is still entirely satisfactory. Echo " break-in " does not occur until the circuit is + 13 db. in each direction.

The sensitivity of the voice operated switch is such that it is usually held operated in one direction or the other by line noise until speech currents operate it normally. As at present arranged the operating time is approximately 7 millisecs. Traffic trials are now being made on the circuit, the operation of which, from the subscriber's point of view, is indistinguishable from that of a normal 4-wire circuit.

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