Oct. 16, 1945. B. M. HADFIELD 2,386,892

SELECTIVE AMPLIFIER OR OSCILLATOR

Filed June 5, 1942 2 Sheets-Sheet 1

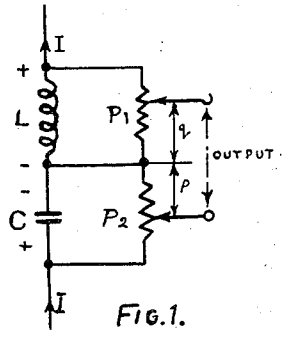


FIG.1.

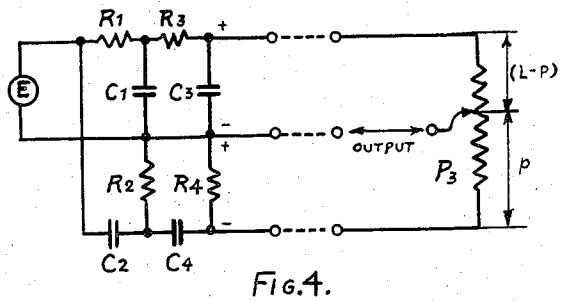


FIG.4.

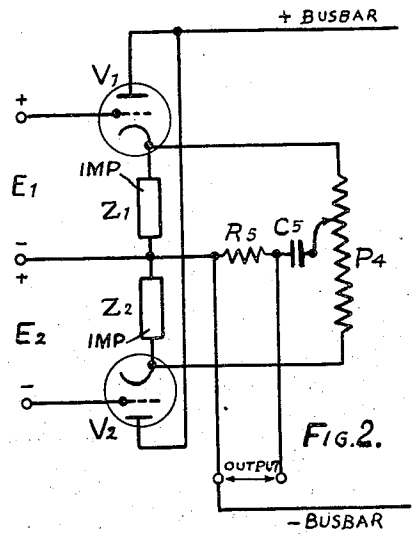


FIG.2.

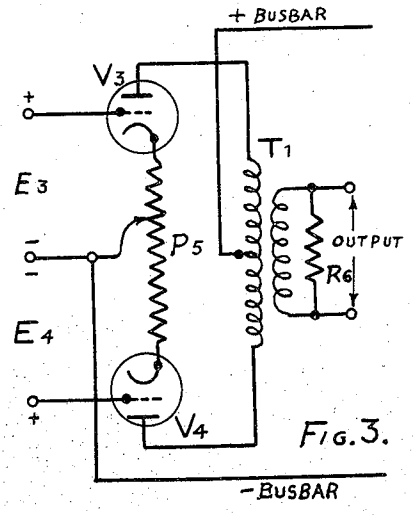


FIG.3.

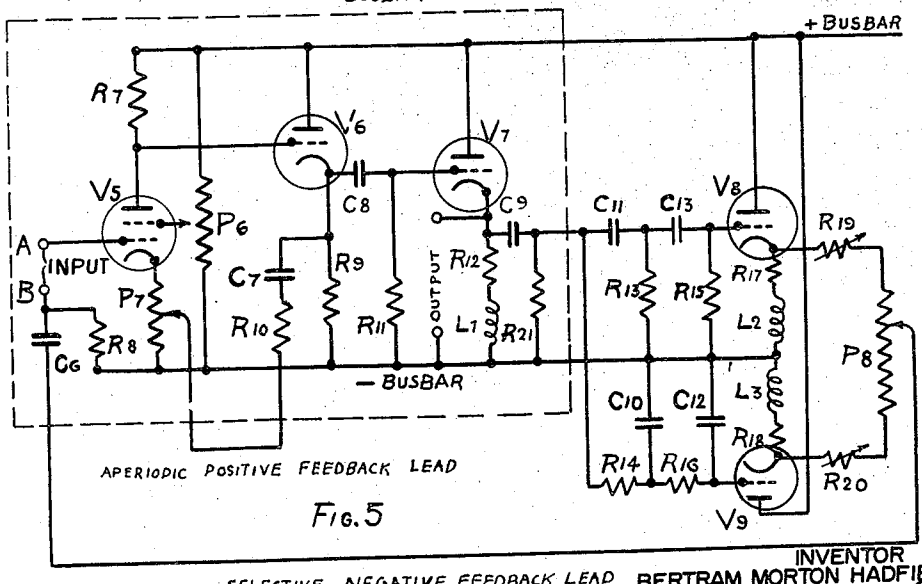


FIG.5

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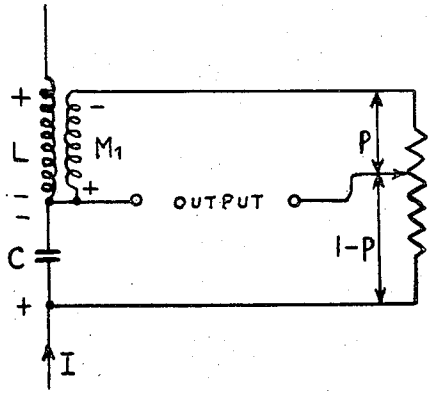


FIG. 6.

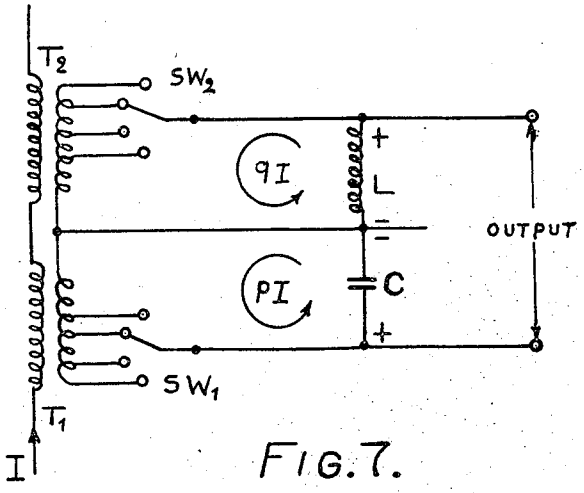


FIG. 7.

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Patented Oct. 16, 1945 2,386,892

UNITED STATES PATENT OFFICE

2,386,892

SELECTIVE AMPLIFIER OR OSCILLATOR

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Application June 5, 1942, Serial No. 445,835
In Great Britain June 23, 1941

5 Claims. (Cl. 250—36)

This invention has reference to circuit arrangements for generating or selectively amplifying electrical oscillations of a given frequency. One of the objects of the invention is to provide a more simple means of control of the given frequency, by adjustment of the amplitudes of voltages of currents in the circuit. A further object is the use of a single means of control, such as a potentiometer, with which a frequency range of some ten to one may be obtained and having a close approximation to a logarithmic frequency scale for linear movements of the control.

The type of generator or selective amplifier of electrical oscillations with which this invention is concerned, is that in which a thermionic amplifier of normal design has an incorporated feedback path which gives substantially no output at the desired frequency. At other frequencies the output is such as to provide a degenerative effect, so that if the original gain of the amplifier be large then a sharply selective frequency response curve is obtained. This form of selective amplifier is well-known and it is also known that if a measure of regenerative feedback be also introduced such that the latter does not materially affect the selective characteristic of the amplifier, then electrical oscillations at the desired frequency will be obtained.

In former examples of this type of apparatus, the feedback path which provides zero output at the desired frequency has consisted of circuit elements containing resistances and reactances and control of the desired frequency has been obtained by simultaneously altering groups of the resistance or reactance elements. It will be seen that this method involves the use of elements which are accurately matched and remain so over the degree of control required. In the present invention, although use of resistance and reactive elements is made in the feedback path, these elements are not used for control purposes and they need not therefore be accurately matched, provided an initial adjustment is made.

The mode of operation of the feedback path in the present invention consists essentially in the provision of two voltages or currents, the magnitudes of which vary in opposite sense with change of frequency and which voltages and currents are always either in phase or out of phase according to the method of construction of the whole circuit. These voltages or currents are then individually applied to gain adjusting devices and the gains adjusted so that at the desired frequency the outputs are equal in magnitude. The outputs are then either added or subtracted according as to whether they are out of phase or in phase respectively, in a common circuit and the resultant output applied to the input of the amplifier in such a manner that a degenerative effect is obtained at any other frequency. It will be seen that by suitable adjustment of the gain devices the output of the feedback path can be made zero at any frequency, thus effecting control of the latter. Further according to the invention it is possible for two gain adjusting devices to be made into the form of a single potentiometer, so that control is only dependent on one adjustment. Also it will be apparent that the gain adjusting devices may be equally effective if they control the inputs to the circuits giving the two voltages or currents. In order that a better appreciation of the invention may be obtained, the following specific embodiments will now be described with reference to the accompanying drawings in which Figure 1 shows a simple form of feedback path employing an inductance and a capacity and embodying the present invention.

Figures 2–4 show details of other forms of feedback path embodying the present invention.

Figure 5 shows the complete circuit in diagrammatic form of a selective amplifier according to the present invention and

Figures 6 and 7 show details of yet other forms of feedback paths.

Any one of the circuits shown in Figs. 1, 4, 6 and 7 may be connected across the output of a suitable amplifier or oscillator with the output terminals of said figures connected to the input terminals of the amplifier or oscillator in the manner shown in Fig. 5.

Reference to Fig. 1 which shows the simplest possible form of the invention will readily enable the objects of the invention to be understood. Practical difficulties in using this form are described later.

Fig. 1 shows a pure inductance L and a pure capacity C connected in series and supplied with a current I which is considered to be constant

irrespective of the impedance variations of the circuit. The instantaneous polarity of the voltages is shown. Potentiometers are connected across the inductance and capacity and the output is taken from the respective arms. The fractional settings are q and p respectively. If w be the frequency of the current I and w_0 the resonance frequency

$$\left(\sqrt{\frac{1}{L.C}}\right)$$

both in radians per second it is obvious that the output is zero when

$$qwL=\frac{p}{wC}$$

and from this we have

$$\frac{w}{w_0}=\sqrt{\frac{p}{q}}$$

If the expression $(1-p)$ be substituted for q in the above equation this obviously means that the arms of the potentiometers are coupled together at equal settings from their top ends, and an approximate logarithmic relationship between frequency and setting for zero output then follows. The relationship can be described as follows: When plotted on a logarithmic scale for frequency

$$\left(\frac{w}{w_0}\right)$$

and a linear scale

$$\sqrt{\frac{p}{1-p}}$$

the curve has a point of inflection at the value unity for

$$\left(\frac{w}{w_0}\right)$$

so that the deviations from any straight line drawn through this value for

$$\sqrt{\frac{p}{1-p}}$$

which is obviously 0.5 are equal for equal ratios on either side thereof. If a straight line be drawn through setting values of 0.9 and 0.1, then the deviations of the curve are negligible over a 10:1 frequency range, from the point of view of approximation to equal percentage reading accuracy over the range.

It has been assumed that the inductance L and capacity C are both free of resistance components. Although close approximations to this state of affairs may generally be obtained in practice this embodiment is not preferred owing to practical difficulties in maintaining such a state.

The above embodiment ensures that the working voltages will be 180° out of phase at all frequencies, if the two potentiometers, arranged respectively across the inductance and capacity, do not affect the voltages as regards magnitude or phase. The relationship between the given frequency and the ratios on the potentiometers can be made to follow any desired law; for instance, if the product p and q be kept constant then there is a linear relationship with p and inversely linear with q.

The relationship between p and q which is preferred, especially when a modification in the potentiometer circuits to be described is made, and which consists of making q equal to $(1-p)$, confers the advantages of the logarithmic form of scale as regards equal percentage reading accuracy, and at the same time the actual calibration of the potentiometers can be made according to a known simple law.

As stated before the arms of the potentiometers could be coupled together for this type of relationship, and this leads to the preferred embodiment whereby a single potentiometer or gain control device is used. If a phase reversal is made in one of the voltages, by for example a secondary winding M1 (Fig. 6) mutually coupled to the inductance then a single potentiometer P can be connected across the remote ends of the inductance and capacity voltages, and a position can always be found for the arm where the voltage between the arm and the join of the voltages is zero. The relationship between the two portions of the potentiometer is of the same form as before and therefore gives a substantially logarithmic variation of frequency for linear movements of the arm.

If the secondary winding has unity ratio then output$=V_L-p(V_L+V_C)=V_L(1-p)-pV_C$. This equals zero when

$$\frac{V_L}{V_C}=\frac{p}{1-p} \text{ or } \frac{wL}{\frac{1}{wC}}=\frac{p}{1-p}$$

or

$$w\sqrt{LC}=\sqrt{\frac{p}{1-p}} \text{ and } \sqrt{LC}=\frac{1}{w_0}$$

As pointed out heretofore, the methods of control may equally well be carried out on the inputs to the circuits. For instance, the inductance and capacity may each be fed with current of adjustable magnitude from separate transformers T_1 and T_2 (Fig. 7) whose primary windings are supplied with a common current and whose secondaries are tapped in accordance with any desired relationship between frequency and tapping points so that the currents in the inductance and capacity may be adjusted to give equal voltage outputs at the desired frequency. The tapping points of transformers T_1 and T_2 are selected by switches SW1 and SW2 such that currents qI and pI flow in L and C respectively where I may be the constant primary current.

$$V_L=wLqI$$

$$V_C=\frac{pI}{wC}$$

Therefore output is zero when

$$wLqI=\frac{pI}{wC}$$

i. e. when

$$w\sqrt{LC}=\sqrt{\frac{p}{q}} \text{ and } \sqrt{LC}=\frac{1}{w_0}$$

As regards the method of control by using one or more potentiometers on the output voltages of the feedback path the connection of such potentiometers without altering the magnitude and phase angles of the voltages, may be effected in any well-known manner. In practice it is found quite possible to use potentiometers of high impedance (say 100 times) compared to the impedances of the circuit elements, but it is generally advisable to apply the output voltage to a thermionic valve arranged as a cathode follower so that the impedance of the circuit applied to the input of the amplifier may be low; this being

particularly desirable where the apparatus is to be used as a selective amplifier.

Alternatively the voltages across the inductance and capacity may be applied directly to the grids of two thermionic valves and the potentiometer connections made to the cathode or anode circuits of the valves.

In order to transform the output impedances of the voltages into lower values without taking current from them, cathode follower stages are used, one for each voltage. Two main types may be employed depending on the polarity of the voltages with respect to their common connection; each type has two alternative methods of connection of the potentiometer wherein the latter may be used as a common internal gain control of the two stages or as an output gain control. Only two versions will be discussed.

Fig. 2 shows a circuit for use where the voltages E1 and E2 are of opposite sign with respect to the common connection (i. e. in series), and the potentiometer P4 is used as an output gain control. Valves V1 and V2 are connected as cathode followers, having large cathode impedances Z1 and Z2 respectively. Thus across the latter there will be available voltages corresponding to E1 and E2 but with the voltage sources now having internal resistances equal to the reciprocal to the slopes of the valves. The potentiometer P4 is connected to the cathodes and the output is taken from the common connection and the arm; the circuit C5, R5 constituting a conventional D. C. voltage eliminator. In this and other circuits employing cathode follower valves, the internal resistances before-mentioned will constitute a portion of the potentiometer, and must be taken into account in the choice of the resistance of the latter and the setting determining the frequency for zero output. Variation of the internal resistance can be mitigated by making the ends of the potentiometer connected to the cathode into small semi-variable resistances, whose value swamps the internal resistances and can be individually adjusted to make up a definite proportion of the potentiometer in conjunction with the internal resistances. This method is generally feasible because if the maximum frequency coverage is limited to 10:1, then there will be 0.09 of the true potentiometer at each end which is never used. This method is illustrated in Fig. 5 where the true potentiometer consists of the two internal resistances of the valves, R19 and R20, and P8. The latter can be designed to cover the 10:1 range (i. e. true settings of 0.091 to 0.91) whilst R19 and R20 are adjusted to constitute the remainder of the true potentiometer in conjunction with the internal resistances.

Fig. 3 shows a circuit for use where the voltages E3 and E4 are of similar sign with respect to the common connection (i. e. in opposition), and the potentiometer P5 is used as an internal gain control. Valves V3 and V4 are connected as cathode followers, using the portions of P5 as cathode resistances. The gains of the valves will be inversely proportional to the resistances of their respective portions of the potentiometer, except for the terminal and finite gains corresponding to the slopes of the valves. Once again the latter can be considered as constituting an effective portion of the true potentiometer and can be dealt with as before. The output is taken from a common anode resistance R6 by means of the centre tapped transformer T1 and will be zero when the ratio of the gains is adjusted to be equal to the inverse of the input voltage ratio.

In Figure 3 this method of gain control is admissible in practice, because when the applied grid voltages become large then the gain must be reduced and hence the design of the circuit from the point of view of grid circuit overloading is facilitated. This latter method of gain control is also possible when the grid voltages are of similar sign, the output then being taken from the anode circuits by means of a transformer the primary of which is connected to the two anodes and a centre tap being taken to the positive battery.

It will be obvious to those skilled in the art that many other modifications in the methods whereby a potentiometer or potentiometers may be used without affecting the voltages applied thereto, are possible and it should be noted that any of these methods may be applied to other forms of the feedback circuits other than the inductance and capacity type described. Another and preferred form of feedback circuit will now be described, with which the output at the desired frequency may be reduced to a zero in a manner superior to the inductance and capacity circuit because of the appreciable resistance components in practical inductances.

As stated before the object of the feedback path is to obtain two voltages or currents of opposite sign independent of frequency and whose magnitudes vary in opposite senses with frequency. Using a source of high impedance and therefore of constant current it does not appear at present possible to obtain increasing magnitude with increasing frequency unless inductances are used. Moreover since it is desirable to let the output stage of the amplifier constitute the source, in order that harmonic production within the amplifier shall be reduced to a minimum (by being degeneratively fed back to the input via the feedback path) then the output stage should preferably be of the low impedance constant voltage type, in order that an external load circuit may be used without appreciably altering the voltage output. Hence the form of feedback circuit which will be described with reference to Fig. 4 will presuppose a source of constant voltage, whose impedance is low compared with that of the circuit at any working frequency. In this form of feedback circuit illustrated in Fig. 4 the source of alternating voltage is E and two seprate paths are used, comprising respectively resistances and capacities R1, C1, R3, C3 and R2, C2 R4, C4 and fed from the common constant voltage source, such that the terminal voltage of one path rises with increase of frequency and the terminal voltage of the other path falls with increase of frequency. The remaining requirement is that the terminal voltages shall be always in or out of phase at any frequency. For instance, one path may consist of elements comprising series resistance and shunt capacity giving the falling frequency characteristic, whilst the other comprises elements of series capacity and shunt resistance giving the rising frequency characteristic. In the design of these paths two alternatives are available, (*a*) the successive elements of resistance and capacity can be of increasing impedance, so that the "loading" effect on the previous element can be ignored, or (*b*) the successive elements can be of substantially the same impedance. In both cases, however, it is found that the time constants of the elements comprising the two paths must be substantially the same and that this time constant determines the geometric mean frequency of the working range in

a similar manner to that of the inductance and capacity feedback path before cited, in which the geometric mean frequency of the working range correspond to the usual resonance frequency.

It can readily be shown that if the time constants of each element comprising resistance and capacity in each path, and in the second alternative that the resistances and capacities comprising a path are respectively equal, then the terminal voltages of the two paths are either in or out of phase at any frequency according to the polarity of the voltage applied to each path. Hence if each path has a common connection then the various potentiometer arrangements heretofore described may be applied to the terminal voltages and the control of the frequency at which zero output is obtained follows in a similar manner.

Furthermore it can be shown that provided one component of each path can be adjusted, then the remaining components need only be of commercial accuracy designed to give time constants of the required order. Actually this will only ensure that the real parts of the voltages meet the requirements, by making the products of the time constants in each path equal to the reciprocal of the square of the desired frequency in radians. In order to cater for the imaginary parts as well, it is necessary to be able to alter the actual time constants in one part, whilst keeping their product constant. This can be arranged, to a sufficient order of accuracy by converting the junction of R1 and R3 in Fig. 4 into a potentiometer forming a small part of the total resistances. The remainder of R1 and a suitable portion of R2 can then be variable and form the aforementioned variable component in each path. It should be noted that a balance test conducted with the potentiometer setting at its midpoint will be concerned with the imaginary parts and that a test at a setting at one end of the potentiometer will be mainly concerned with the real parts. In this manner it is easy to check the correct balance conditions. When the two paths have been assembled complete with any one of the potentiometer arrangements, it is found that adjustment of the semi-variable component in each path gives zero output at the desired frequencies according to the setting of the potentiometer arrangement and as heretofore described.

The location of the potentiometer arrangement may be at the output voltages of the two paths, at any convenient intermediate point in the paths, or at the voltages applied to the paths, since the only effect of the potentiometer is to provide a multiplying factor on the voltages present in each path. For instance, the common point of the two paths may be connected to the arm of a potentiometer whose ends are connected to the constant voltage source, thus giving control of the voltages applied to each path. This method is not preferred in practice, as the source impedance for each path is varied according to the setting of the potentiometer unless the potentiometer is of very low impedance, and consequently the output is not quite zero at the desired frequencies and potentiometer settings other than that at which the paths have been adjusted.

Fig. 5 gives a detailed circuit including a suggested form of amplifier shown within dotted lines, which has been found to be satisfactory in practice. In general this circuit may take the form of any amplifier of conventional type, the requirements being an output impedance which is negligible compared with that of the feedback paths, the phase of the output to be opposite to the input in order that the feedback to the input shall be negative at all other frequencies, no self-oscillating frequency with 100% feedback, a reasonably constant amplitude response and negligible phase change over the desired operational frequency band, and as large a gain as is practicable. The latter is desirable as the selectivity of the whole circuit is directly dependent upon the gain. In addition and when used as an oscillator, there must be a positive feedback path.

The selective feedback circuit is comprised by C11, R13, C13, R15 on one side and R14, C10, R16, C12 on the other side, being fed from the output of the amplifier with alternating voltage (in the present case a D. C. eliminating circuit C9 and R21 is necessary, owing to the direct path via the lower side). The potentiometer circuit is of the form shown in Fig. 2 where L2 and L3 replace Z1 and Z2; R17 and R18 constitute self bias resistances for valves V8 and V9 and may be made up by the D. C. resistances of L2 and L3. As mentioned before R19 and R20 are small variable resistances designed to constitute the unused ends of the true potentiometer in conjunction with the internal resistances of the valves. The selective negative feedback lead is taken from the arm of the potentiometer P8 to the input of the amplifier via a D. C. eliminating circuit C6, R8.

The amplifier that is shown employs a valve of the high slope pentode type for V5, but any convenient type may be used. The amplification provided by valve V5 is a maximum by using a high anode resistance R7 and some cathode negative feedback from the resistance of the potentiometer P7. The screen voltage is adjusted by P6 so that with the grid bias provided, overloading takes place simultaneously on positive and negative anode voltage excursions, being due in the positive sense to grid current in V6 and in the negative sense to anode overloading of V5. V6 is arranged as a cathode follower, the cathode resistance R9 being designed so that grid current shall take place at the appropriate anode voltage of V5. The alternating voltage on R9 is fed to the grid of V7 via C8 and R11. V7 constitutes the output stage and is also of cathode follower type to give a minimum of internal impedance, the cathode impedance being L1 and whatever load resistance is placed across the output terminals. The latter is limited by the necessity for ensuring that grid current in V7 occurs at a higher voltage than in V6; R12 is the self bias resistance for V7 and may be constituted by the D. C. resistance of L1. The positive feedback is taken from R9 to P7 via the D. C. eliminating circuit C7 and R10. This path is preferably aperiodic in nature over the working frequency range, if the frequency characteristics of the amplifier are also aperiodic; if not, then this path must be modified so that the degree of positive feedback remains sufficient just to give oscillation over the whole frequency range, when used as an oscillator. The positive feedback ratio may be adjusted by alteration of the potentiometer P7. The input terminals A. B. which are shorted when in use as an oscillator, enable the circuit to be used as a selective amplifier; the positive feedback being reduced to zero, of course by P7.

The valve V7 constitutes the low impedance source one terminal of which is connected to a common busbar or return lead of the two selec-

tive frequency paths as heretofore described in connection with Figure 4, whilst the other terminal is connected to the remaining two input leads of the two paths. The output voltages of the two paths are then of opposite polarity with respect to the common busbar, and the latter may form the negative busbar of the battery supplying the ampl'fier. Hence, provided the direct current conditions of the amplifier are met in any well-known manner, a potentiometer may be connected across the output leads of the two paths and the alternating output between the arm and the busbar applied to the input of the amplifier, so that at frequencies other than the desired frequency the feedback is degenerative. The form of the potentiometer may be of any of the appropriate types described and the output therefrom may, if desired, be taken via an impedance transforming device such as a valve arranged as a cathode follower. In the embodiment shown in Fig. 5 the coupling impedances of the amplifier, whether stray or intentional, are reduced to a minimum, and any frequency characteristic of the amplifier is mainly due to the stray capacity across the anode load resistance. If the grid bias of the first valve is derived from a cathode resistance, then it is possible to increase the frequency at which this stray capacity is effective by placing a shunt capacity across the cathode resistance; at the expense, of course, of the maximum gain. A value of cathode capacity giving approximately equal cathode and anode time constants is suitable. Also by designing the amplifier to overload simultaneously on equal positive and negative output alternations only odd harmonics are appreciably generated, and the degenerative action of the feedback path becomes more effective in producing a sinusoidal output. Furthermore both overload points are closely related with the battery voltage so that stability of output voltage will be ensured by the normal precautions applying to the provision of a steady battery voltage. As is well-known for this type of generator or selective amplifier, the output voltage and current is only limited by the battery voltage and the type of output valve.

From the above description of the invention it will be seen that the accuracy of control of the desired frequency is dependent on the accuracy with which a potentiometer may be controlled and calibrated.

A ten to one range of frequency has been suggested as suitable for coverage by the potentiometer, owing to the relatively small deviation from a logarithmic frequency scale. It will be apparent, however, that by using further groups of feedback circuits designed for other geometric mean frequencies the effective range of the invention can be expanded at will, and provided these further ranges are made convenient multiples then a common scale can be used. There is a further reason why it is inadvisable to cover much more than a ten to one range with the potentiometer, which should be borne in mind when deciding on the minimum gain of the amplifier. This is that the "gain" of the feedback path to frequencies other than the desired frequency varies with the potentiometer setting. For instance, with a fractional setting of 0.5 the maximum voltage output at very high or very low frequencies is obviously 0.5 of the input voltage. A loss of 6 db. therefore occurs in the maximum possible degenerative effect of the amplifier and feedback path. Similarly with a setting of 0.1 or 0.9 a loss of 20 db. occurs at frequencies respectively below or above the desired frequency (assuming that frequency is proportional to these setting figures, as heretofore shown). Provided that the amplifier has sufficient gain (say 50 db.) this effect is not of great importance as regards harmonic suppression, since the minimum degenerative effect can be kept to some 30 db.

The invention as described is not restricted in its applications to any particular band of frequencies, except by consideration normally applicable to the design of high gain amplifiers having feedback paths, that is, stray capacities and inductances and impurity of the components. By using well-known technique therefore, the invention may be applied to any desired range of frequencies and may be adapted for use in wireless receiving or transmitting sets, or in carrier or audio frequency telephony or telegraphy.

No difficulty has been found in the application of the invention apart from that common to all such similar devices, that is, the design of an amplifier to give a reasonable gain without having instability at high frequencies when used with 100% negative feedback. The circuit described is free from this defect and is capable of a gain of 50 db. The coverage of any number of frequency bands can be effected merely by changing the fixed condensers in the feedback path. No instability of voltage output was obtained even when using a battery supply operating switchgear. Frequency stability and waveform were as good as with other types of oscillators in general use. The cost of this oscillator should be considerably less than most types as the variable elements are reduced to one which is of easily manufactured type, whilst the bulk is correspondingly smaller.

I claim:

1. An amplifier or oscillator including an input circuit and an output circuit, a circuit path associated with the output circuit for deriving a voltage therefrom which varies in one sense with changes in frequency, another circuit path associated with the output circuit for deriving another voltage therefrom which varies in the opposite sense with corresponding changes in frequency but remains in phase opposition to the first voltage, adjustable means for combining the derived voltages in variable proportions and applying the resultant voltage to the said input circuit to provide a degenerative feedback which becomes zero at any desired frequency determined by the adjustment of said means whereby the oscillator frequency or the frequency to which the amplifier is selective may be controlled by said means.

2. An oscillator having a regenerative feedback, means for deriving a voltage from the oscillator which increases with an increase of the frequency therein, means for deriving a second voltage from the oscillator which decreases with an increase of the frequency therein, a circuit for combining the derived voltages and applying the resultant voltage to the input as a degenerative feedback, the circuit for combining the derived voltages comprising a potentiometer so connected that the feedback may be reduced to zero at any desired frequency by adjustment of said potentiometer.

3. An amplifier having an input and an output, a circuit for obtaining a voltage from the output which increases with an increase in the frequency of the current flowing in the amplifier, and for obtaining another voltage which decreases with

an increase in the frequency of the current flowing in the amplifier, another circuit for combining the voltages obtained and applying the resultant voltage to the input as a degenerative feedback, said other circuit for combining the derived voltages comprising a potentiometer so connected that the feedback may be reduced to zero at any desired frequency by adjustment of said potentiometer.

4. A network comprising inductance and capacitance, or resistance and capacitance, elements which may be connected to a source of varying frequency, deriving two voltages therefrom which vary in magnitude in opposite senses with changes in frequency while maintaining the same phase relationship, means for applying the derived voltages in series to a potentiometer and obtaining a resultant voltage from an adjustable tap on said potentiometer and a common connection for the two derived voltages, said resultant voltage becoming zero at any desired frequency depending on the adjustment of said potentiometer.

5. An amplifier or oscillator having an input and an output, a circuit arrangement of condensers and resistors associated with the output for deriving two voltages therefrom which vary in magnitude in opposite senses with changes in frequency while maintaining the same phase relationship, means in bridge of said condensers and resistors for adding the voltages and applying the resultant voltage to the input to provide either a zero or degenerative effect according to the frequency, said means comprising a potentiometer the adjustment of which determines the frequency at which the zero effect occurs and thus determines the oscillator frequency or the frequency to which the amplifier is selective.

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