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2,463,073

OSCILLATOR

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Fig. 1.

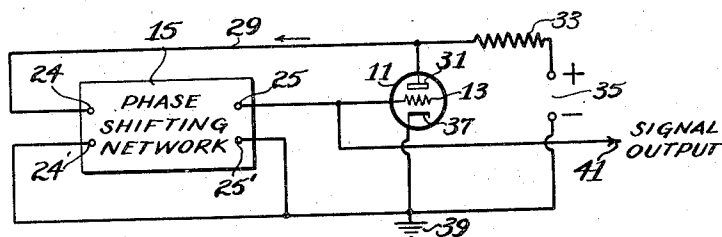


Fig. 2.

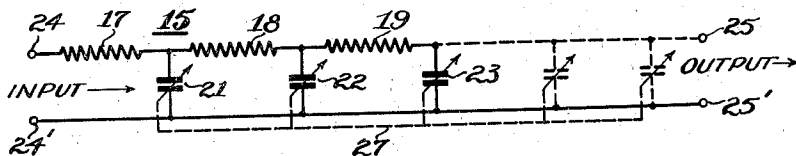


Fig. 3.

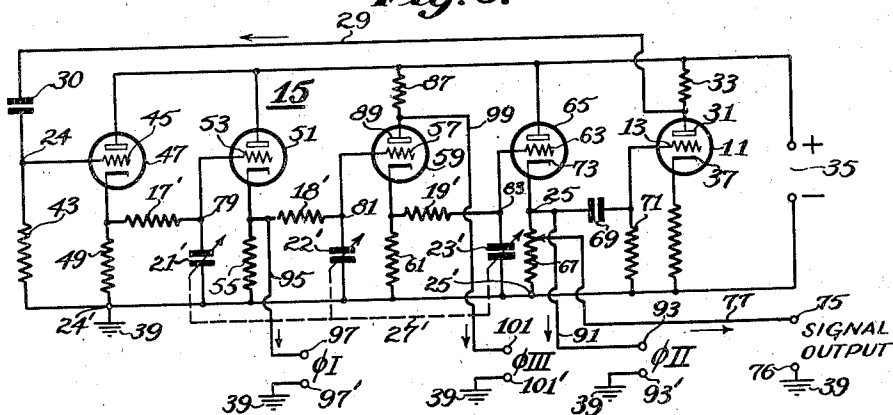


Fig. 5.

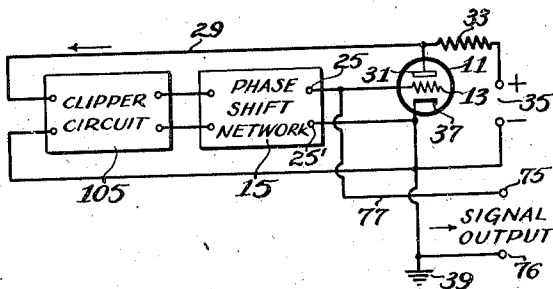
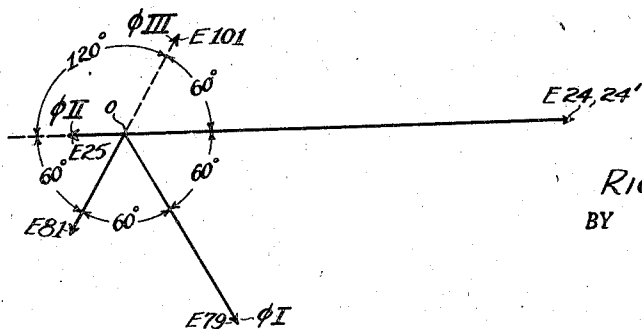


Fig. 4.



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OSCILLATOR

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7 Claims. (Cl. 250—36)

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This invention is related to electronic oscillators. In its more particular form, the invention is related to a variable frequency electronic oscillator of the general type known as the resistance tuned arrangements. In its simplest and most practical form, the oscillation frequency which is developed in an oscillator of this character is determined by a combination of resistance and capacity elements only.

The invention herein to be set forth and described is further particularly characterized through the use in it of a form of phase shift circuit wherein a so-called ladder type network is utilized to form a feedback path between the output terminals and the input terminals of a vacuum tube amplifier. In its particular form, the invention provides an improved form of ladder type network which offers many economical, theoretical and practical advantages over heretofore known forms of resistance and capacity networks when used as a feedback path in a phase shift oscillator.

In the past various circuits have been utilized to provide the effect of phase shift and essentially, these circuits utilized were either series resistance and shunt capacity elements forming a ladder type network or series capacity and shunt resistance elements also forming a ladder type network, with the former circuit constituting a low pass filter arrangement and the latter constituting a high pass filter arrangement. In all such uses of circuits of this character, it became evident that while various forms of resistance and capacity elements would fit the requirements necessary to provide the controlling elements for a phase shift oscillator, they did not always function in a satisfactory manner because of the loading of the circuits, as will hereinafter be set forth, and because of the fact that in most instances, the limit frequencies which could be realized from circuits of this character were not such as to enable these circuits to find wide application.

In all circuits of the prior art utilizing the phase shift principle and a resistance and capacity network, it was necessary to meet satisfactorily two basic requirements of which one was that the product of the gain of the amplifier and the transmission response of the selected phase shift network should be made at least equal to unity and preferably greater than unity; and, second, that the total phase shift around the complete circuit must be 360 electrical degrees (2π radians) or an integral multiple thereof. It is well known, of course, that in such circuits a 180° phase is always provided by the vacuum tube

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amplifier between its input grid and its output plate circuit and, accordingly, the remaining 180° phase shift required to meet the oscillating conditions must be provided by the phase shift network.

These oscillators of the prior art had certain outstanding advantages and came about as a result of utilizing the resistance and capacity elements over circuits utilizing the beat frequency oscillators. Among these advantages were the facts that the phase shift oscillator provided a great degree of freedom from frequency drift and made it unnecessary to continually check the calibration. Other advantages came about because of the fact that it was possible to provide a uniformly good wave form output and yet to provide a considerably more compact, lighter and cheaper oscillator than would be possible with the beat frequency oscillator. However, the prior art arrangements have been of such variety that either all of the capacity elements or all of the resistance elements of the ladder network are usually in series and formed as the result of combining a plurality of usually three or more filter sections of either the high pass or the low pass type.

The frequency of oscillation in a system of this type is varied by providing suitable means to control the value of either or both the capacity and resistance elements. Where recourse is taken to the use of a low pass filter to form the phase shifting network, it is evident that because of the increased attenuation this type of network offers to harmonics of the oscillating frequency, there is a considerable tendency for nonlinear distortions generated within the feedback amplifier to be greatly reduced in magnitude after passage through the filter network with the result that the wave form finally resulting at the output terminals is considerably improved. Likewise, since the circuit constants or parameters of the phase shifting network must be varied in order to change the resulting frequency, the network constants are automatically adjusted to give the same loss characteristics to these harmonics at any frequency to which the oscillator may be adjusted. This becomes a particularly significant feature when consideration is given to the design of adjustable filters to follow a standard variable frequency oscillator.

With these forms of oscillators being known, the present invention incorporates as additional features and as elements serving to stabilize the oscillator and to improve its range and operating characteristics the use of a number of filter

sections, usually at least three, with cathode follower tubes connected between each section of the filter network and at its input and its output ends. A cathode follower tube used in such connection between each section of the phase shifting network improves the operation to the extent that the phase shifting elements in the network can be considered as being driven from a substantially zero source impedance and operating into an effectively infinite load resistance, which is in contrast to the already described arrangements of the prior art wherein each section is operated out of the effective impedance of the preceding section or sections and is loaded by the impedance of each of the succeeding section or sections. As a result, the frequency range to which the oscillator herein to be described may be tuned is increased substantially over that which was heretofore obtainable.

With the foregoing characteristic features having been generally described, it becomes an object of the present invention to provide a resistance and capacity phase shift oscillator circuit of improved operating stability and waveform characteristics which shall be effective over a wide frequency range.

A further object of this invention is the utilization of circuit constants and tube elements in such a way as to improve the frequency characteristics of a phase shift network.

Still a further object of the invention is the provision of an oscillator circuit from which separate output voltages are readily obtainable at the correct phase shift relations to obtain polyphase output signals from the system.

A further object of the invention is to provide cathode follower tubes to interconnect different sections of either low pass or high pass filter combinations with the cathode follower tubes being connected in such a way as to improve the operation and stability of the oscillator.

Other objects and advantages of the invention are those of providing an oscillator circuit which is relatively simple in its arrangement and construction; the provision of an oscillator circuit which is positive in its operation and which is effective over a wide frequency range; the provision of an oscillator circuit which overcomes one or more known defects of the prior art and which, at the same time, is highly efficient in its use and operation and which is relatively inexpensive to install, light in weight and compact from the space requirements.

Other objects and advantages of the invention will, of course, become apparent and those suggest themselves to those skilled in the art to which the invention is directed when the following specification and claims are considered in the light of the appended drawings wherein:

Fig. 1 is a schematic representation of a phase shift oscillator; Fig. 2 is a diagrammatic representation of one form of suitable phase shifting network; Fig. 3 represents one form of circuit for practicing the invention in accordance with the present disclosure; Fig. 4 is a vectorial representation of the phase shift effects obtained in the network of Fig. 3; and Fig. 5 is a schematic representation of the general form shown by Fig. 1, with the addition of a clipper circuit to provide signal limiting.

Referring now to Fig. 1 for a further understanding of the invention, the phase shift oscillator tube 11 is arranged to receive impressed signal voltages on its input grid or control electrode 13 from an appropriate form of the phase

shifting network 15. One form of the phase shifting network, as shown by Fig. 2 particularly, comprises an arrangement of series resistance elements 17, 18, 19 and so forth, bridged by parallel condenser elements 21, 22, 23, etc., all located intermediate the input terminals 24, 24' and the output terminals 25, 25'. The circuit arrangement of Fig. 2 will thus be seen to comprise essentially the form of a low pass filter network and to provide for frequency variances when used in the oscillator of Fig. 1, for instance, when the resistance and capacity combinations are appropriately changed in value. The various condenser elements 21, 22, 23, etc., are connected to be driven together so that the capacities increase and decrease simultaneously under the influence of a single control element which has been conventionally indicated by the uni-control connection provided by way of the linkage 27. With the phase shifting network of this general type, input signals (as in Fig. 1, for example) are supplied to the terminal 24 by way of the conductor 29 connected to the plate or anode 31 of the tube 11 and across the output resistor 33. Plate voltage is supplied to the tube 11 by way of a source (not shown) connected intermediate the terminal points 35, with the source being poled as indicated. The cathode 37 of the tube 11 connects to ground 39, as indicated, and output signals are derived at output terminal 41, which is connected across the output terminals of the phase shifting network.

The phase shifting network shown particularly by Fig. 2 and schematically represented by Fig. 1 at 15 is such that a phase shift of substantially 180° is applied to the signals between the input terminals 24 and 24' and the output terminals 25 and 25' at some established frequency. A like phase shift of 180° is produced within the tube 11 between the grid 13 and the plate or anode 31 for all frequencies within the audio or supersonic range. Thus, where the product of the gain in the amplifier tube 11 and the transmission response of the phase shifting network 15 is equal to or greater than unity and the total phase shift around the complete circuit is exactly 2 π radians (360 electrical degrees or an integral multiple thereof), it is apparent that oscillations will be developed.

It is evident that the frequency of these oscillations will be dependent upon the values given to the resistance elements and the capacity elements, as indicated in Fig. 2, and the oscillation frequency can readily be determined mathematically by well-known formulae. In arrangements of this character, it is apparent that a phase shift of 180°, for instance, occurs between the input terminals and the output terminals, as in Fig. 2, but, also, it is apparent that each section of the filter, that is, for instance, the section comprising the resistance 17 and the condenser 21, is loaded by all other sections following it. Accordingly, the phase shift in each section of the filter or phase shift network of Fig. 2 is non-uniform. The circuit arrangement of Fig. 3, accordingly, provides, in addition to the elements shown to accomplish phase shift as in Figs. 1 and 2, several vacuum tubes used to divide the filter sections in appropriate manner.

Referring now to the phase shift or filter network and the phase shift oscillator of Fig. 3, the separate filter sections of Fig. 2, which are utilized in Fig. 3, are identified by like reference numerals with a prime attached. Also, the sec-

tions of the filter which are separated from each other by virtue of the inclusion of several thermionic vacuum tubes will readily also be identified. To this end, the phase shift oscillator tube 11 has its operating voltage applied between the plate 31 and the cathode 37 again supplied from a source (not shown but conventionally represented at 35) with the plate load resistor again being represented as 33. Signal voltages from the tube 11 are fed back to the input of the phase shifting network by way of the conductor 29 and the D. C. isolating condenser 30 so as to appear at the input terminals 24 and 24' across the grid resistor 43 which serves as a connection and grid return between the grid element 45 of the first tube 47 of the phase shifting network and ground 39.

Signal voltages applied to the input terminals 24 and 24' (see Fig. 3) appear at the grid 45 of the tube 47. This tube has the first filter or phase shift section 17' and 21' connected to it in cathode follower fashion. The cathode resistor 49 of the tube 47 serves to conduct the cathode current of the tube to ground 39. This resistor plays no appreciable part in the total resistance of the phase shifting unit connected to the tube since the resistance 49 is in shunt with the low internal resistance of the cathode follower tube.

It is a well known fact that the effective internal resistance of the vacuum tubes when connected in cathode follower fashion is, in general, an approximation of the reciprocal of the usual grid-to-plate transconductance of the tube. Thus, with tubes of the type generally now used, this internal resistance may be considered as a very low value (for instance, 500 ohms or less) and, accordingly, it is negligibly small in comparison with the value of the resistance elements, such as 17, 18 and 19, for instance, which are used in the various sections of the phase shifting network 15.

Considering further the portion of Fig. 3 so far discussed, it will be seen that the tube 47 having the first phase shifting network section 17' and 21' connected to it in cathode follower fashion has the further property of having an unusually high input resistance for its grid circuit. Thus, the phase shifting network section 17', 21' can be considered as being driven from a substantially zero source impedance and operating into an effective infinite load resistance in the form of the next succeeding tube 51, to the input grid 53 of which the output of the first phase shifting network section is connected. At once it becomes evident that the individual section 17' and 21' of the phase shifting network of Fig. 3 varies from that shown by Fig. 2 in that it operates into effectively an infinite load resistance, whereas the first phase shifting network section 17 and 21 of Fig. 2 was loaded by the impedance of the succeeding sections 18, 22 and 19, 23, and so on.

Continuing the consideration of the circuit of Fig. 3, the cathode element of the tube 51 connects to ground 39 through a cathode resistor 55 having the same general characteristics as the cathode resistor 49 associated with the tube 47. The next section 18' and 22' of the phase shifting network connects in cathode follower fashion with the tube 51 across the cathode resistor 55 and feeds its signal output voltage to the grid 57 of the next cathode follower tube 59. This cathode follower tube has its cathode connected through a cathode resistor 61 to ground, as indicated. The resistance 61 has the same func-

tion with tube 59 as already pointed out in the discussion of the operation of tubes 47 and 51 and the resistors 49 and 55 used therewith.

If it be assumed that the phase shifting network 15 comprises three separate phase shifting sections, then, the third section comprising the resistor 19' and the capacity 23' is connected in cathode follower fashion with the tube 59 and across the cathode resistor 61 to feed its output signal upon the grid or control electrode 63 of the last tube 65 of the assembly. The tube 65 again has its cathode connected to ground through the cathode resistor 67, and output signals from the phase shifting network are then applied upon the control grid 13 of the tube 11 by way of the coupling condenser 69 and across the grid resistor 71 which connects from grid 13 to ground 39. This coupling circuit is assumed to contribute no phase shift of its own.

With the three filter sections assumed being connected with the tubes 47, 51 and 59 in cathode follower fashion, it will be appreciated that if a 180° phase shift is to occur between the signals impressed at the input terminals 24 and 24' and those available at the output terminals 25 and 25', then a 60° phase shift must occur in each individual filter section if uniformity is to result. With each filter section being so connected that it is driven from a substantially zero source impedance and is arranged to feed into an effectively infinite load resistance, as shown, it will be seen that a uniform and substantially equal phase shift occurs in all sections.

The last tube of the assembly connecting the last filter section output to the tube 11 introduces no phase shift in that the signal voltages appearing at the cathode 73 are in phase with those available at the grid 63 and no phase shift occurs in the coupling between the cathode output of the tube 65 and the input to the tube 11. Thus, with the tube 11 being arranged to amplify and to take care of the losses introduced by the cathode follower sections of the phase shifting network, it will be appreciated that the aforesaid conditions to sustain oscillations may readily be provided so long as the gain of the tube 11 and the transmission response of the complete phase shifting network, including the various tubes 47, 51, 59 and 65, together with the phase shifting network sections, is such that the product is greater than unity and the phase shift around the complete circuit is equal to 360° or an integral multiple thereof. Signal outputs at the frequencies which are measured and determined by the selected values of capacity and resistance in each phase shifting network section are made available at the output terminals 75 and 76 as derived by way of conductor 77 adjustably connected to the cathode resistor 67 of the tube 65.

The circuit arrangement of Fig. 3, it will be noted, provides fixed resistor elements 17', 18' and 19' with adjustable capacity elements 21', 22' and 23' in order to provide the low pass filter network type of phase shift section. Adjustment of the capacity elements will provide changing frequency values and, obviously, where adequate frequency change is not realized from the fixed values of resistances assumed and diagrammatically shown, it will be appreciated that several different resistor sections may be connected in parallel, and with an adjustment of the condenser 21, there may also be provided adjustments whereby like value resistance sections connect between the cathodes of the various tubes and the grids of the next succeeding tubes with un-

used resistance sections all being connected to ground. Also, it will be appreciated that within the scope of this invention, the phase shift effect may be brought about by virtue of high pass filter sections replacing the low pass filter sections indicated in which capacity elements will be located in positions in the phase shifting network corresponding to the locations of the resistances shown, and resistance elements will be substituted in the locations shown for the capacity elements. In either instance, the phase shift between the input terminals and the output terminals is still provided as the 180 electrical degrees necessary provide for sustained oscillations.

The foregoing oscillator thus is highly stable and readily controlled as to frequency by a mere adjustment of all the condenser elements 21', 22' and 23' simultaneously by virtue of the uni-control arrangement of 27'. Further, the oscillator herein shown is such, as above explained, that a uniform phase shift occurs in each section of the filter. Accordingly, with the three-section filter being provided and a 180 electrical degrees phase shift being introduced between the input terminals and the output terminals, it may be appreciated that a 60° phase shift occurs in each section, provided the value of all the resistances 17', 18' and 19' is kept equal and the value of all the capacity elements 21', 22' and 23' is similarly maintained equal. With this in mind, reference may be made to the diagrammatic showing of Fig. 4 where the input voltage available in the input terminals 24 and 24' may be assumed to be represented by the vector $O-E_{24}$. The voltage applied to the input of the tube 51 after passing through the phase shifting network 17' and 21' and being retarded with respect to the input voltage may be assumed to be that voltage represented at the point 79 and, accordingly, represented by the vector $O-E_{79}$. Similarly, the voltage available at the input of the tube 59, after the input signal has been passed through the phase shifting network 18' and 22' will be that voltage which appears at the point 81 and which is applied to the grid 57 and, hence, is represented by the vector $O-E_{81}$. Lastly, the voltage available after passing through the third phase shifting network 19' and 23' is applied to the input or control grid 63 of the tube 65 in accordance with the voltage which appears at the point 83, and, accordingly, is 180° out of phase with regard to the input voltage at the input terminal 24 and applied to the grid 45 of the tube 47. Since no phase shift occurs between the input grid 63 and the cathode 73 of the tube 65, the voltage available at the grid 13 of the tube 11 is that voltage which appears at point 25 and is represented by the vector $O-E_{25}$. Because the cathode follower connected tubes are herein utilized and because the amplification provided by each of these tubes is less than unity, the voltages are all reduced in magnitude in excess of the amount that naturally occurs in passage through each phase shifting element and the vectors represented by the diagram of Fig. 4 are intended to indicate schematically both the phase displacement and the assumed relative magnitude of the various voltages.

It was pointed out above that a phase shifting network of the character generally described might readily be utilized for the development of polyphase output signals at any frequency to which the oscillator is to be tuned. If reference is now made further to the showing of Fig. 3 with the vector diagram of Fig. 4 in mind, it will

be appreciated that the voltage represented by the vector $O-E_{79}$ is 120° out of phase with regard to the voltage represented by the vector $O-E_{25}$ so that, accordingly, if it be assumed that the voltage represented by vector $O-E_{25}$ constitutes one of the three phases, a second phase may readily be obtained from the voltage represented by the vector $O-E_{79}$. It also will be observed that the voltage represented by the vector $O-E_{81}$ is out of phase with each of the voltages $O-E_{25}$ and $O-E_{79}$ by 60°, lagging $O-E_{79}$ by 60° and leading $O-E_{25}$ by 60° so that if now a voltage be obtained which is 180° out of phase with regard to the voltage $O-E_{81}$, the obtained voltage will be 120° out of phase with regard to each of the voltages $O-E_{25}$ and $O-E_{79}$. It was above pointed out that the voltage $O-E_{81}$ is that which appears at the input grid 57 of the tube 59 and since it is a well known fact that a 180° phase shift occurs within a vacuum tube between the grid and plate electrodes, it will be appreciated that the voltage appearing across the load resistor 87 connected to the plate 89 of the tube 59 is 180° out of phase with respect to the input voltages supplied to this tube. Accordingly, with the vector diagram of Fig. 4 in mind, the conductor 91 may be connected across the cathode resistor 67 of the tube 65 to supply to the terminal points 93 and 93' voltages in phase with the voltage represented by vector $O-E_{25}$ and representing one phase (marked ϕI) of a three-phase supply.

Likewise, from what has been stated above, there will be supplied to a conductor 95 connected across the cathode resistor 55 of the tube 51 to supply the terminal points 97 and 97' a voltage wave which is in phase with the voltage represented as the vector $O-E_{79}$. Thus, at the terminals 97 and 97' a second phase (marked ϕI) of a three-phase supply is made available. Likewise, there is supplied to the conductor 99 connected to the terminal points 101 and 101' a third phase (marked ϕIII) which is derived in accordance with the voltage appearing across the load resistor 87 connected to the tube 59. To utilize the developed voltages represented as ϕI , ϕII and ϕIII , it is only necessary to equalize these voltages by means of simple potentiometers (not shown for simplicity of illustration) and adjustment of the voltage amplitudes can readily be accomplished in well known manner without in any way affecting the phase relationship of the developed voltages at any frequency within the range of the oscillator.

While the invention above described, particularly in connection with Fig. 3, shows three-phase operation assumed, it should be understood that any number of phases may be developed if desired. This is readily accomplished by changing the number of sections in the network. The development of polyphase voltages is not possible with the arrangement of Fig. 2 because there the loading per section is not uniform due to the loading of one section upon another section. The arrangement of Fig. 3, when thus providing the three separate phases, makes it possible to utilize the oscillator together with suitable power amplifiers to control the speed of rotation of synchronous or induction motors and makes readily possible all of the advantages of three or more phase operations of such devices, as well as utilization of the circuit hereinabove described in connection with the operation of Selsyn or Autosyn indicators, timing and control circuits, circular sweeps for cathode ray tubes, and the like.

The foregoing description has set forth par-

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particularly the low pass filter type of phase shifting network rather than the high pass type above briefly mentioned. It will be appreciated in this connection that the low pass type of phase shifting network has certain advantages not present in the high pass type of network which, for example, would be particularly emphasized by the increased reduction of harmonic content present in the output signal developed across the resistor 33 as the output from the tube 11 which is to be fed back by way of conductor 29 to the phase shifting network. The use of the cathode follower tubes 47, 51, 59 and 65, for instance, also tends to improve the operation from the standpoint of both the low pass filter and the high pass filter type of phase shifting network. Where the low pass type of filter phase shifting network, as herein disclosed, is utilized, the harmonics present in the developed signal are reduced by passage through the resistor elements before again applying the signal to the grid of the feedback tube 11 whereas if the high pass type of network is utilized, the series capacity elements often tend to effect an accentuation of the harmonics so as thereby to tend to increase the total distortion present in the oscillating signal.

Amplitude limiting of the developed signals to control the maximum amplitude of the oscillations present in the circuit is desirable under many operating conditions. Accordingly, in a circuit of the type shown by Fig. 3, for instance, it becomes convenient at times to take advantage of the improved filtering action of the low pass filter type of phase shifting network in conjunction with a suitable form of signal limiter or clipper circuit immediately preceding the phase shifting network. A circuit of this general form has been schematically and diagrammatically represented by Fig. 5 where the feedback connection 29, from the feedback tube 11 is shown as connecting into a clipper circuit 105 which has been diagrammatically shown.

The clipper circuit 105 receives the feedback signal and passes the output to the phase shifting network 15. The remaining portion of the circuit operates as shown and described by Fig. 3. The clipper circuit conventionally shown at 105 is of any well known form of clipper and limiter. It serves as a signal gate to clip symmetrically both the positive and negative half cycles of the signal wave fed back by way of conductor 29 as soon as that wave reaches a predetermined threshold value. A symmetrically clipped sine wave of the character developed in the circuit of Fig. 3, for instance, will then be found to contain the fundamental frequency component plus harmonics which are odd multiples of the fundamental wave, with the odd harmonics progressively decreasing in amplitude relative to the fundamental with very considerable decrease of the higher harmonics. Furthermore, the amplitude of the fundamental increases but very little above a predetermined threshold limit even in spite of the removal of substantial top and bottom sections of the wave by clipping action. The harmonic components introduced by the clipping action are reduced to negligible size due to the filtering action of the low-pass network.

The clipper circuit included within the unit 105 may comprise any form of circuit and tube instrumentality so constituted as to provide both grid and plate limiting, for instance, so that with the clipping effected, an extremely rapid action form of amplitude control is obtainable. In this

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connection, it should be pointed out, however, that the effectiveness of the amplitude control produced by the clipping circuit 105, as shown in Fig. 5, is of maximum effect only when the oscillator is used as a single phase source of signal voltage with the output signals derived at the output terminals 75 and 76 because, under these circumstances, the filtering effect or action of the phase shifting network is utilized to its fullest extent only when the signal is permitted to pass through the complete network between its input terminals 24 and 24' and its output terminals 25 and 25'.

Where the oscillator is used for the generation of three phase voltages, the signals should be removed, as indicated by Fig. 3, and an amplitude control circuit utilizing the usual diode rectifier or AVC system is to be preferred. A circuit of this type would then offer the advantage of permitting no distortion to occur at any point of the circuit and the signals from each section of the phase shifting network will be equally free of harmonic content.

In the light of the foregoing description, it will be apparent that various modifications may be made in the circuit herein shown without in any way departing from either the spirit or scope of what has herein been set forth, and, accordingly, it is believed that such modifications as fall fairly within the spirit and scope of what is hereafter claimed may readily be made.

Having now described the invention, I claim:

1. An electronic oscillator circuit including, in combination, a feedback tube having an input circuit and an output circuit, a phase shifting network comprising a filter including a plurality of separate sections of resistance and capacity elements, said filter having its input circuit connected to receive the output signals from the feedback tube and its output circuit connected to supply signals to the input circuit of the feedback tube, and a thermionic tube connected between each separate section of the resistance and the capacity filter element, said individual filter sections each being connected with individual tubes in cathode follower manner to provide a low impedance source to drive each section of the phase shift network, the complete phase shift network and tube combination being so arranged that the signal voltages passed therethrough arrive at the output of the filter in opposite polarity to the signal voltages at the output of the feedback tube.

2. An electronic oscillator circuit including, in combination, a thermionic feedback amplifier tube having an input circuit and an output circuit, a phase shifting network comprising a filter including a plurality of separate sections of resistance and capacity elements, said filter having its input circuit connected to receive the output signals from the feedback tube and its output circuit connected to supply signals to the input circuit of the feedback tube, and a thermionic tube connected between each substantially like section of the resistance and the capacity elements of the phase shifting network, said individual network sections each being connected to said tubes to receive input signal voltages from the immediately preceding tube in cathode follower manner to provide a low impedance source to drive that section of the phase shift network, and to deliver output signal voltages to the input circuit of the next succeeding tube, so that a phase shift is introduced between the input and the

output of the complete phase shifting network and tubes to supply the signal voltages passing therethrough to the input of the feedback tube in opposite polarity from the signal voltages available at the output of the feedback tube.

3. The circuit claimed in claim 2 comprising, in addition, means to derive output voltages each bearing a predetermined phaseal relationship to each other and each of like frequency.

4. An electronic oscillator circuit including, in combination, a thermionic feedback amplifier tube having an input circuit and an output circuit, a phase shifting network comprising a plurality of substantially like characteristic separated sections of resistance and capacity elements having the input circuit thereof connected to receive output signal voltages from the feedback amplifier tube and the final output circuit thereof connected to supply phase shifted signal voltages to the input circuit of the feedback amplifier tube and also adapted to supply output signal voltages to a load circuit, a thermionic tube connected between each separated section of the resistance and the capacity phase shifting network, said tubes each having the individual section of the said phase shift network connected thereto in cathode follower fashion to provide a low impedance signal source for the next succeeding section of the phase shift network so that a substantially equal phase shift is introduced in each network section and so that the signal voltages passed through the phase shifting network to the input of the feedback amplifier tube arrive at the said input in opposite polarity from the signals at the output of the feedback tube, whereby oscillations are developed at frequencies dependent upon the magnitudes of the resistance and capacity elements forming the phase shifting network.

5. An electronic oscillator circuit including, in combination, a thermionic feedback tube having an input circuit and an output circuit, a phase shifting network comprising a plurality of isolated sections of resistance and capacity elements, said network having its head end portion connected to receive output signal voltages from the feedback tube and its output end portion connected to supply signal voltages to the input circuit of the feedback tube, a thermionic tube sequence of which one tube is connected between each of the plurality of sections of the resistance and the capacity network, said individual network sections each being connected to receive the output signal voltages from the immediately preceding tube in cathode follower manner and to deliver its output to the next thermionic tube of the sequence and the complete phase shifting network and tube combination being so arranged that the signal voltages passed therethrough arrive at the output of the network in opposite polarity to the signal voltages at the output of the feedback tube.

6. An electronic feedback oscillator circuit including, in combination, a thermionic feedback tube having an input circuit and an output circuit, a multi-section phase shifting network of which each section includes at least one resistance and capacity element, said complete phase shifting network having its input end connected to receive output signal voltages from the feedback tube and its output end connected to supply

signal voltages to the input circuit of the feedback tube, a separate thermionic tube connected between each individual section of the resistance and the capacity phase shifting network, said individual network sections each having the input thereto connected with a preceding and individually associated thermionic tube in cathode follower manner and the output of each network section being connected to supply signal voltages to the input circuit of the following thermionic tube, the last network section being connected to supply signal voltages to the feedback tube and the complete phase shift network and tube combination being so arranged that signal voltages passed therethrough arrive at the output of the network and at the input of the feedback tube in opposite polarity to the signal voltages at the output of the feedback tube.

7. An electronic oscillator circuit including, in combination, a thermionic feedback amplifier tube having an input circuit and an output circuit, a phase shifting network comprising a plurality of separate substantially like sections of resistance and capacity elements having its input circuit connected to receive output signal voltages from the feedback amplifier tube and its output circuit connected to supply phase shifted signal voltages to the input circuit of the feedback amplifier tube and also adapted to supply output signal voltages to a load circuit, a thermionic tube connected between each separate section of the resistance and the capacity phase shifting network, said tubes each having a phase shift network section connected thereto in cathode follower fashion to produce a low impedance source to drive each section of the phase shift network so that a substantially equal phase shift is introduced in each section of the phase shifting network and so that the signal voltages passed through the phase shifting network to the input of the feedback amplifier tube arrive at the said input in opposite polarity from the signals at the output of the feedback tube, whereby oscillations are developed at frequencies dependent upon the magnitudes of the resistance and capacity elements forming the phase shifting network, and a plurality of output connections for obtaining separate phase shifted voltages all at like frequency.

RICHARD C. WEBB.

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