June 8, 1948. P. WEATHERS 2,443,125

OSCILLATOR

Filed Dec. 11, 1946

Fig. 1.

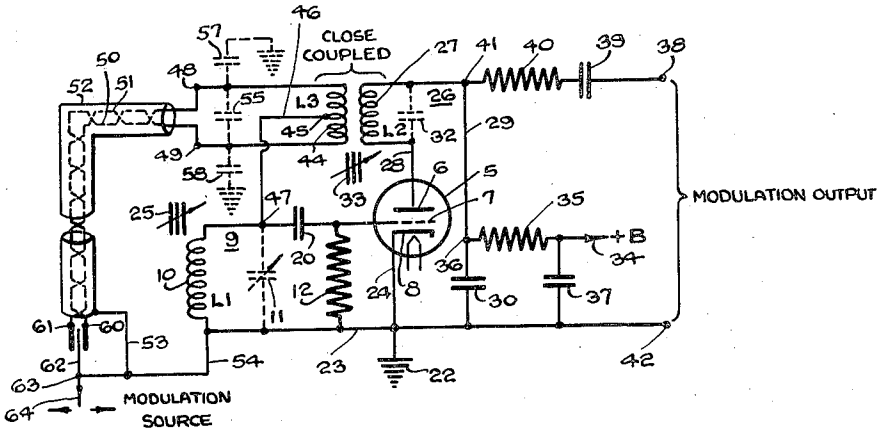


Fig. 2.

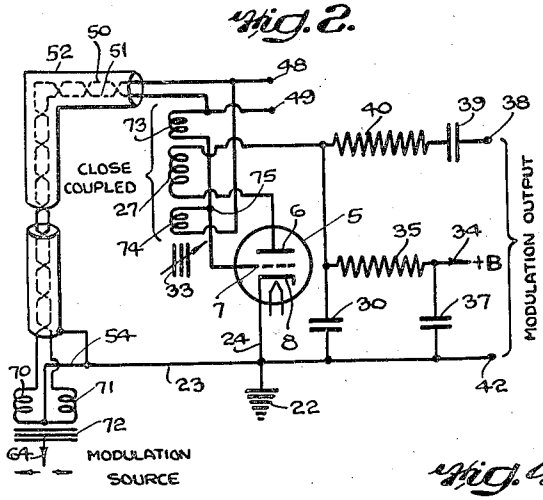


Fig. 3.

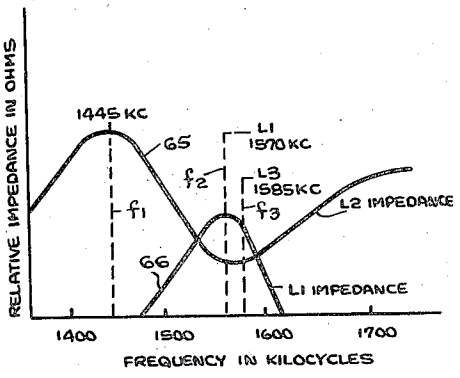
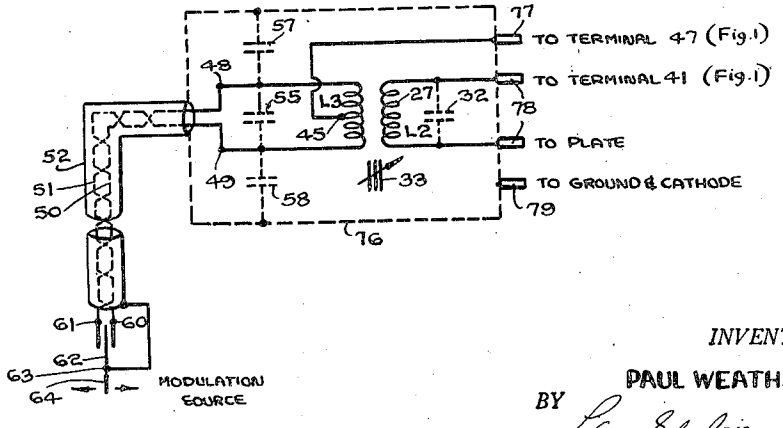


Fig. 4.



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OSCILLATOR

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Application December 11, 1946, Serial No. 715,377

12 Claims. (Cl. 179—171.5)

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The present invention relates to oscillators of the electronic tube type, and more particularly to self-excited, modulated oscillators of the electronic tube type as shown, described and claimed in my copending application Serial No. 636,702, filed December 22, 1945, for Oscillators, Patent Number 2,436,139.

In the oscillator system referred to, a self-excited, electronic-tube oscillator is provided with circuit means for effecting variable control of oscillation strength or modulation effect thereon and a resultant amplified modulation signal output. Modulation is applied to the oscillator in response to extremely small changes in capacity, inductance or resistance in a control circuit coupled with the oscillator, and includes the control of feedback currents differentially to effect an accentuated variation in the bias potential applied to the grid of the oscillator at the modulation frequency rate. This results in an enhanced variation in anode current and in the modulation output signal derived from such variation.

It is an object of the present invention, to provide an improved method and means for controlling an electronic-tube oscillator of the self-excited type by modulation, whereby a greatly amplified modulation signal may be derived therefrom in response to extremely small changes in capacity, inductance or resistance in a control circuit coupled with the oscillator, and without applying the modulation signal to the grid of the oscillator.

It is also an object of the present invention, to provide an improved electronic-tube oscillator system of the self-excited, modulated type referred to, wherein the modulation control effect thereon and the modulation voltage or signal output is of high fidelity and greatly increased beyond values heretofore attainable.

It is a further object of this invention, to provide a self-excited, electronic-tube oscillator system having a modulation control circuit for varying feedback from the plate circuit to the grid circuit, in-phase and counter-phase with respect to a normal feed-back for maintaining oscillations, which provides an accentuated variation in the input capacity of the oscillator and a resulting variation in the tuning of the oscillator grid circuit, thereby to vary the magnitude or strength of the oscillations without appreciably varying the frequency of the oscillations produced, whereby a greatly increased high fidelity modulation signal output is attained.

It has been found that a system of this type may produce a voltage variation or modulation

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signal component at the output or anode circuit, of greater magnitude and higher fidelity than has heretofore been possible with the oscillator system referred to and with the same relatively small variation of capacity, resistance or inductance in the control circuit. It is also therefore, well adapted for use in high fidelity phonograph record reproduction systems.

The modulation source may comprise a small, light-weight, push-pull variable capacitor or any variable impedance, and the oscillator and associated circuits may be coupled thereto through a transmission line of appreciable length, without introducing undesired modulation effects and without appreciably limiting the frequency range of response of the impedance element, or the amplitude of the controlling effect upon the oscillator and the fidelity of the resulting signal output therefrom.

It is, therefore, a still further object of this invention, to provide an improved, self-excited, electronic-tube oscillator system which operates to vary the feed-back of energy from the anode circuit to the grid circuit without appreciably varying the frequency of oscillation and wholly in a condition of under neutralization responsive to variations in the input admittance of the tube.

The effect of variation input admittance or capacity, of the type referred to, is shown in Terman—Radio Engineers' Handbook, 1943, McGraw-Hill Book Company, pp. 467 et seq. and in Figure 92 on page 470.

Further in accordance with the invention, the variation in input capacity or admittance is caused to be amplified or accentuated and to produce an amplified controlling effect upon the anode current in the output circuit of the oscillator from which the modulation signal component is derived.

The modulation source is coupled to the oscillator through a balanced-to-cathode or ground transmission line or control circuit which is extremely sensitive to capacity, inductance or resistance changes at its terminal end, and operates to control the flow of energy from the anode circuit to the grid circuit of the oscillator by differential control of the coupling. In this manner a greatly increased variation in anode current or output potential is provided and a relatively great modulation effect is produced upon the oscillator in response to relatively minute variations in capacity, inductance or resistance at the terminal end of the control circuit.

In a preferred embodiment of the invention, having a modulation control circuit above de-

scribed, the grid circuit of the oscillator is coupled to the anode circuit through the intermediary of a coupling winding or feed-back inductance which controls the frequency of the anode circuit and of the oscillator by means of relatively tight inductive coupling with the oscillator anode circuit and the reflected reactance from the control circuit into the anode circuit.

The grid circuit, conductively coupled to the control circuit or feed-back inductance, is made responsive normally, to a frequency of the order of but slightly higher than that of the oscillator.

This response or resonance frequency varies with modulation, but has little effect on the oscillator frequency. Thus with a system embodying the invention, variation in the input capacitance of the oscillator merely varies the response frequency of the grid circuit and the strength of oscillations, thereby modulating the oscillator and providing a variation in anode current greatly amplified and in exact reproduction of the modulation signal, for higher fidelity of response to the modulation applied to the oscillator control circuit.

Furthermore, the control of feed-back current from the anode circuit through the control circuit inductance is such that a differential inphase and counter-phase inductive feed-back is provided on the grid circuit to vary the amplitude of oscillations and the relative resonance frequencies of the grid and anode circuits by reflected reactance.

Viewed in one of its aspects, the modulation control circuit may be considered to vary the feed-back or degree of neutralization of the oscillator, thereby to vary the input admittance or capacity, and the strength of oscillations to a high degree, in response to small variations in the impedance of the control circuit effected by the modulation source.

The invention will, however, be more fully understood from the following description when considered in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the drawing:

Figure 1 is a schematic circuit diagram of an electronic-tube, modulated oscillator system embodying the invention in a present preferred form;

Figure 2 is a further schematic circuit diagram of an electronic-tube, modulated oscillator system embodying the invention, and showing a modification of the circuit of Figure 1; and

Figure 3 is a graph showing curves illustrating certain operating characteristics of the circuit of Figure 1;

Figure 4 is a still further schematic diagram of a portion of the circuit of Figure 1, arranged as a self-contained unit detachable and independent of the remainder of the system and the oscillator tube, and adapted for plug-in connection therewith, as in the circuit of Figure 1.

Referring to Figure 1, 5 is an electronic oscillator tube of the thermionic type having an anode 6, a control grid 7 and a heated cathode 8. Between the grid and the cathode is connected a tuned grid circuit 9 comprising a variable tuning inductance 10 and shunt tuning capacity indicated at 11, the latter comprising mainly the reflected grid-to-plate or anode capacity, C_{gp}, of the tube, together with stray capacity and the grid-to-cathode capacity of the tube.

A grid resistor 12 and grid capacitor 20 are connected in the grid circuit 9 for maintaining operational bias on the tube in response to oscillations. The cathode is connected to ground for the system as indicated at 22 and through a lead 23, and grid 7 is also connected to ground and to the lead 23 as indicated by the connection 24.

The capacity represented at 11 comprises the sole tuning capacity for the input circuit 9, and accordingly the inductance element 10 may be made relatively high in inductance value, and the variable tuning or adjustment of the initial frequency response of the circuit 9 is accomplished by varying the inductance 10, preferably by a movable tuning core 25 which may be of ferromagnetic or other suitable material.

A similar tunable circuit 26 is connected between the anode and ground, and comprises a variable tuning inductance 27 connected to the anode through a circuit lead 28 and to cathode and ground through a circuit lead 29 and a bypass capacitor 30. The shunt tuning capacity for the circuit 26, schematically indicated at 32, is provided by the plate-to-cathode and plate-to-grid capacities of the tube but mainly by a reflected reactance through the inductance 27 to the circuit 26. As in the case of the grid circuit, the anode circuit frequency response or tuning may be adjusted to a desired resonance by varying the inductance 27, by means of a suitable movable tuning core indicated at 33.

Anode current is supplied to the oscillator from a positive supply lead 34 through an output coupling impedance or resistor 35 and the inductance 27, the resistor 35 being connected at 36, between the bypass capacitor 30 and the inductance 27. The supply lead 34 is also provided if desired, with a suitable bypass or filter capacitor indicated at 37. A modulation or audio frequency signal output terminal, indicated at 38, is connected with the anode circuit at 41 on the high potential side of the output coupling impedance 35, through a coupling capacity 39 and a filter impedance 40 in series. The opposite terminal of the output circuit is indicated at 42 and is connected to ground and cathode as indicated. This arrangement provides for deriving signal output at the modulation frequency across the impedance element 35 as the result of anode current variations at the modulation frequency.

When the grid and anode circuits 9 and 26 are resonated at different frequencies of the same order or value, by adjustment of the respective tuning cores 10 and 33, the tube 5 will oscillate because of energy feedback across the high inductance 27 through the grid-to-plate capacity, C_{gp}, from the circuit 26 to the circuit 9. When the tube oscillates, the anode current flow through the resistor 35 decreases because of an increase in negative bias on the oscillator grid 7 established by the grid current flow through the grid resistor 12, until a steady state of oscillation is established. The oscillator is thus self-excited and tends to oscillate at a fixed frequency determined largely by the circuit constants in the anode circuit.

Feed-back from the anode circuit to the grid circuit is produced through external means comprising a feed-back inductance 44 coupled to both the grid circuit and the anode circuit.

A coupling connection from an intermediate point or center-tap 45 thereon is provided, by means of which it is coupled to the grid circuit 9 through a connection lead 46 terminating with a connection 47 with the high potential or grid side of the grid circuit 9. The tap 45 is preferably at the electrical or inductive center of the

winding 44. On the anode side of the coupling, the feedback inductance 44 is closely coupled electromagnetically with the inductance 27 in the anode circuit, whereby feed-back current or energy from the anode circuit may flow therethrough to the grid circuit.

Means are also provided in connection with the feed-back inductance for conveying feed-back current or energy from the anode circuit through said inductance differentially, to provide differential in-phase and counter-phase inductive feedback of energy to said grid circuit thereby to vary the amplitude or strength of oscillations of the oscillator and to control the relative resonance frequencies of the circuits connected with the inductances 10, 27, and 44 by reflected reactance in the anode circuit and input capacity variation, as will hereinafter be described.

The terminals 48 and 49 of the feed-back inductance 44 are connected to a transmission line forming part of the oscillator modulation control circuit, and comprising a pair of closely associated insulated leads 50 and 51, preferably twisted together, and enclosed within a conducting shield 52, which is connected to the cathode return lead and ground of the oscillator through suitable ground leads indicated at 53 and 54.

A substantially fixed capacity is provided in connection with the terminals 48 and 49 by the leads 50 and 51. This capacity is effectively connected in parallel with the feed-back inductance 44 as indicated by the dotted capacitor 55, thereby serving to tune the inductance 44 to a predetermined frequency.

The shield element of conduit 52 surrounding the leads 50 and 51, provides additional tuning capacity effectively in parallel with the feed-back inductance 44. This is the stray capacity between each of the twisted leads of the cable and the shield element 52, the components of which are indicated at 57 and 58.

The value of the shunt capacity 55 remains substantially fixed in response to shifting of the cable in the shield or movement with respect to the system ground and cathode connection. This however, changes both of the capacity values indicated at 57 and 58 substantially equally and in the same sense. Therefore, the overall change in capacity balance is effectively zero and no appreciable modulation or noise effect is produced upon the system.

The terminal end of the transmission line is connected to variable control means or a modulation source providing inversely variable impedance paths to ground or cathode for the control circuit leads 50 and 51. The modulation source shown in the present example is a push-pull variable capacitor having fixed electrodes or plates 60 and 61 connected with the terminal ends of the leads 50 and 51, respectively. A movable electrode or plate 62 is located between the fixed plates and pivoted as indicated at 63, for oscillation betwen said fixed plates to vary the air gaps on each side thereof inversely and correspondingly to vary the electrical impedance of the circuits connected with the fixed plates 60 and 61 to ground or cathode. In the present example the plate 62 is actuated by suitable movable stylus means indicated at 64. The electrode 62 is preferably located substantially midway between the plates 60 and 61 in a normal condition of rest and is connected as indicated, to the lead 54 for completing a circuit path through the capacity or impedance of the modulation means to ground of the oscillator system, as shown.

The cable or transmission line represented by the leads 50 and 51 and the associated shield, may be extended to a considerable distance without appreciably increasing the capacity 55 between the leads beyond that which is required to resonate the anode inductance 27, by reflected reactance through the feed-back inductance 44, within a desired frequency response range. This range is determined by the desired operating frequency of the oscillator.

It will be seen therefore, that the feed-back inductance 44 is provided at its terminals with balanced feed-back paths to ground or cathode which provides a balanced positive and negative feed-back through the feed-back inductance which may be varied differentially to modulate the oscillator. Full modulation control of feedback through the inductance 44 to the grid circuit may be realized by the use of a relatively small capacity change such as provided by a movable metallic reed at 62 of relatively small dimensions, when vibrated at relatively low amplitude between similar small electrodes at 60 and 61, although said electrodes may be relatively widely spaced.

To provide such small capacity or impedance change for controlling large and effective feedback of energy the feed-back inductance 44 is tightly coupled to the anode circuit inductance 27 whereby the reactance of the circuit connected therewith is reflected over into the anode circuit 26 and serves to tune the same to the desired frequency of oscillation for the oscillator. Furthermore, the exchange of energy from the anode circuit 26 to the grid circuit 9 upon slight movement of the controlling element at the modulation source is caused to be highly effective because of the resonance condition existing between the two circuits. It will be seen that as the flow of energy or current with respect to the tap 45 through one winding portion increases the flow through the other winding portion decreases proportionately thereby enhancing the control action or modulation range for push-pull action.

The oscillator circuit may utilize a high-mu triode tube such as a commercial type 6SF5 or 6SQ7 in the simplified form of the circuit as shown. Furthermore, all inductances such as 10, 27, and 44, also hereinafter referred to and designated in the drawing at L1, L2 and L3, respectively, may have essentially the same inductance and therefore may be the same electrically and physically, and be wound to the same diameter and size, for low cost manufacture.

The grid inductance L1 is tuned by the grid-to-plate capacity *Cgp* of the tube at 11 as hereinbefore referred to, plus the capacity of the inductance element L3 to ground, since the latter is connected directly with the grid circuit 9 through the connections 46 and 47. In addition, the capacity to ground, 57 and 58, of the attached leads or control circuit 50—51, affects the tuning of the grid circuit 9, by reason of the same connection.

The inductance L3, that is the feed-back inductance, is tuned by the capacity 55 of the control circuit leads in shunt therewith. Variation in tuning response of the circuit 26 may be effected by movement of the tuning core 33, as hereinbefore pointed out. In the circuit 26 the anode circuit inductance 27 may be considered to be substantially untuned, but by reason of the close coupling with the inductance L3, and adjustment of the core 33, it is resonated at the desired oscillator frequency by the reflected re-

actance from the control circuit and L3 over into the anode circuit at 32.

The oscillator becomes self-oscillating at a predetermined operating frequency, hereinafter referred to as *f1*, by the relatively high anode inductance provided at 27 which causes feed-back from the anode circuit to the grid circuit through the normal plate-to-grid capacity *Cgp*. The anode circuit in the present example may be considered to be tuned to an operating frequency, *f1*, for the oscillator, of the order of 1445 kc. The feed-back circuit of L3 may be considered to be tuned for response at a frequency *f3*, which may be of the order of 1585 kc. in the present example.

The grid circuit is tuned for response at a higher frequency which may be designated as *f2*, and may be considered, by way of example, to be of the order of 1570 kc. Thus both the grid circuit response frequency and the operating frequency of the anode circuit are of the same order, with the grid circuit having a slightly higher frequency response than the oscillator operating frequency.

The anode circuit inductance L2 further may be considered as a high inductance coil tuned to resonance by the associated capacities and reflected reactance and in series between the anode and the modulation output circuit. Being tightly coupled inductively to the feed-back inductance L3, which is in the modulation control circuit, the reflected capacity or reactance at 32 of L3 across L2, tunes L2 to the frequency *f1* (1445 kc.) and establishes the operating frequency for the oscillator. With this arrangement it has been found that variation of the tuning of the grid circuit 9 and of L1 has substantially no effect upon the frequency of the oscillations of the oscillator but only serves to vary the strength or intensity of the oscillations.

Referring to Figure 2 and curve 65, the variation in impedance of L2 with variations in frequency is indicated. This curve is plotted between relative impedance in ohms and frequency in kilocycles, as shown. It will be seen that the plate impedance L2 is maximum at 1445 kc. which is the operating frequency *f1* and is minimum in the region of 1585 kc. which is the adjusted resonance frequency *f3* of the feed-back inductance and associated circuit leads. This provides a maximum feed-back of energy from plate to grid, and maximum oscillation strength at the oscillator operating frequency *f1* of 1445 kc. The impedance of the grid circuit inductance is indicated by the curve 66 in Figure 2, for a steady-state condition of oscillation. It will be noted that this resonance or impedance curve is spaced in frequency above the operating frequency *f1*. It has been found that the inductance L1 of the grid circuit must always be tuned for response at a frequency *f2* above frequency *f1* for proper operation of the system, as will hereinafter be described.

The operation of the system is as follows: Assuming the oscillator to be energized, the anode circuit 26 is tuned as hereinbefore pointed out to the normal operating frequency, *f1*, and the grid circuit 9 is tuned for response or to resonate at a higher frequency, *f2*, which is of the order of or higher than the frequency *f1*. Feed-back of energy from the anode circuit through the normal grid-to-anode capacity path maintains the oscillator in a steady state of oscillation at the frequency *f1*. The average anode current flowing through the output coupling impedance 35 assumes a constant normal value, and with substantially no variation in average anode current, the modulation signal output at the terminals 36 and 42 is zero. Radio frequency energy from the anode circuit is prevented from appearing at the output terminals by reason of the bypass capacitor 30 and the impedance 40 connected with terminal 38.

Feed-back current or energy at the frequency of the tuned anode circuit 26, flows by inductive coupling through the feed-back winding 44 substantially equally on either side of the intermediate tap 45. Feed-back current of energy may be considered to flow in a path which may be traced from the terminal 45 through the connection 46 and the grid circuit inductance 10, thence through the ground connection and the movable electrode 62, thence through the electrodes 60 and 61, the cable connections 50 and 51 back to the terminals 48 and 49 of the inductance 44.

It will be seen that when the control circuit through the leads 50 and 51 and the modulation source 60, 61 and 63 is balanced, that is when the impedance to ground in connection with the terminals 48 and 49 is equal, the opposing potentials induced from the inductance 27 through coupling with the feed-back inductance 44 are equal and opposite in phase, whereby the steady state of oscillation is maintained without change.

Variation of the impedance element at the control end of the modulation circuit connected with the inductance 44, causes a variation in the impedance between ground and one or the other of the terminals 48 and 49, thereby causing unbalance in the potentials applied to the terminal 45 and differentially a flow of in-phase or counter-phase feed-back energy to the grid circuit, thereby increasing or decreasing the strength of oscillations.

This is by reason of the fact that when the feed-back of energy through the feed-back inductance 44 is varied, an increase in feed-back from the anode circuit in one direction will aid, and in the opposite direction will oppose, the normal feed-back from plate to grid by in-phase and counter-phase action. Therefore, simplified and effective means are provided for conveying feed-back current from the anode circuit through the feed-back inductance differentially, thereby varying the amplitude of oscillations and the signal output in response to modulation control of the variable impedance means at the modulation source.

Considering the effect of the feed-back variation as a variation in neutralization of the oscillator, in response to variations in feed-back through the inductance 44 responsive to operation of the modulation source, it will be seen that feed-back in one direction will increase, and in the opposite direction will decrease, the condition of neutralization, and the effective input capacity across the grid circuit will vary in a corresponding manner, thereby varying the strength of oscillation, while the frequency established by the anode circuits remains constant.

Furthermore, as the effective input capacity increases, the resonant frequency of L1 is lowered and more closely approaches the frequency *f1* as will be seen by further reference to Figure 2. Therefore, the magnitude or amplitude of the oscillations will increase by reason of this tuning effect upon the response frequency of the grid circuit. Likewise, as the effective input capacity decreases, the resonance frequency of L1 will increase and depart more widely from the operat-

ing frequency *f1*, in which case the magnitude or amplitude of the oscillations will decrease.

In either case, the change is such as to cause the oscillator to build up an amplification of the change or to enhance the effect of variation of feed-back, and therefore provides active dynamic response to the modulation control in either direction of change to a greater degree and more effectively than has heretofore been possible.

With reference to Figure 2, it will also be seen that L1 must be sufficiently tuned above L2 in frequency, or above the operating frequency of L2, to permit full modulation without approaching closely to the frequency of *f1*. This is for the reason that it has been found that when L1 is tuned too closely to L2 in frequency response, oscillations at the modulation frequency will take place and this appears to be caused by L1 shifting in tuning at the modulation frequency.

The grid admittance of the oscillator and particularly the input capacity component thereof, is of importance, since the tube is operated in what may be considered to be an under neutralized state and is caused to operate with a variable input capacity in turn causing a variation in neutralization, in accordance with the characteristics described in the publication hereinbefore referred to.

Variation of the impedance elements at the terminals of the control circuit, in this case, differential variation in capacity between the ground and the control circuit of the feed-back inductance 44, may be considered to cause variation in the state of neutralization of the oscillator, as the impedance of the control circuit through one portion or the other of the feed-back inductance 44 is varied with respect to the center-tap connection 45 for the grid circuit.

The normal state of neutralization and the high impedance plate circuit causes steady state oscillations to be maintained however, and the state of neutralization is caused to approach and recede from the range of over neutralization, and thereby causes the input capacity across the grid circuit inductance L1 to vary. This variation is indicated by the arrow associated with the schematic capacity 11.

Summarizing the foregoing description of the operation: The strength or magnitude of oscillation is varied in response to operation of the modulating means thereby causing variation of feed-back energy from the anode circuit to the grid circuit in aiding or opposing relation with respect to the normal feed-back which establishes and maintains oscillation, therefore causes variation in the input capacity of the tube as above described, and this effect in response to the push-pull or differential variation of the control circuit impedance causes the resonated frequency of L1 to vary accordingly toward and away from the frequency of *f1*, thereby enhancing and amplifying the modulation action. The variation of tuning of the grid circuit, however, has been found to have substantially no effect upon the frequency *f1* of the oscillator, which is maintained substantially constant by the tuned anode circuit of L1 sustained by the reflected reactance from the circuit of L3.

Therefore, variation of the tuning of the grid circuit by variation of the input capacity only varies the magnitude or strength of the oscillations. Hence, in this system, modulation is effected by varying the strength or magnitude of the oscillations by varying the input capacity of

the oscillator tube in response to differential variations of feed-back from the anode circuit to the grid circuit with respect to the normal feed-back for a steady state, self-excited condition of oscillation, while the anode circuit tuning maintains a constant frequency of oscillation.

The voltage drop across the series anode or plate impedance 35 is correspondingly varied at the modulation frequency and the modulation component of the signal is derived across said impedance through the filter impedance 40 and the coupling capacitor 39. The modulation signal output may then be applied to any suitable utilization means, not shown, from the terminals 38 and 42.

In the transfer of energy from the anode circuit to the grid circuit it should be noted that the bypass capacitor 30 also provides a low impedance path for the R.-F. energy feed-back through the cathode circuit to permit maximum transfer of energy from the anode to the grid.

A further function of this capacitor, in conjunction with the impedance element 35, is to provide a low pass filter for all desired modulation frequencies, having a rising frequency characteristic at the high frequency end of the modulation frequency range and just before modulation frequency cut off. This is effected by the combination of capacity and resistance in the plate circuit at this point and it is preferable that the time constant of the filter arrangement be such that high frequency accentuation takes place just before high frequency cut off.

In the system described, the grid circuit inductance L1 is not inductively associated with the inductance L2 and L3. It may be connected permanently in the grid circuit and may be associated with the oscillator system, whereas the inductance elements L2 and L3, being closely coupled, may be maintained separately and spaced from the grid circuit inductance L1 and other portions of the oscillator circuit as will hereinafter be described.

The modulation source for the circuit shown in Figure 1 may comprise variable inductance elements or other forms of variable impedance adapted for connection between the terminal ends of the transmission line or control circuit and ground for the system. Furthermore, the feed-back coupling inductance 44 and the grid circuit inductance 10, that is L1 and L3, may be combined and connected with the modulation source through the transmission line or control circuit, when the modulation source comprises variable inductance elements.

In Figure 3, to which attention is now directed, the system of Figure 1 is shown schematically, with the modification above referred to, and for ready comparison, like parts and circuit elements in Figure 3 bear the same reference numerals as in Figure 1.

In Figure 3, it will be seen that the modulation source is of the variable inductance type comprising an inductance winding 70 connected between the control lead 50 and the ground return leads 54—23, and a similar inductance winding 71 connected between the control lead 51 and the ground return leads 54—23. The windings 70 and 71 are arranged in push-pull parallel relation in a position to be differentially controlled by movement of an associated ferro-magnetic core element, indicated at 72, in response to movement of a modulation member or stylus 64 which in operation moves in the direction of the arrows.

Movement of the core element 72 in one di-

rection serves to increase the impedance of the winding 70 while decreasing the impedance of the winding 71, and in the opposite direction increases the impedance of the winding 71 while correspondingly decreasing the impedance of the winding 70, thereby varying the relative impedances of the two branches of the control circuit and the feed-back effect as in the proceeding example.

The oscillator end of the control circuit 50—51 is connected with terminals 48 and 49 and with the feed-back inductance the two opposing portions 73 and 74 of which are separated as shown and located in closely coupled relation with the anode inductance 27 at opposite ends thereof.

The grid 7 is connected directly to the intermediate or mid-tap point on the feed-back inductance as indicated at 75. Since the inductance elements may all be of the same inductance value and size as referred to hereinbefore, the inductance elements 73 and 74 plus the modulation inductance elements 70 and 71 respectively, in series therewith to ground and cathode, the grid circuit impedance is therefore provided for without additional inductance element. Likewise, the grid resistor and capacitor are eliminated by this arrangement so that the overall circuit is greatly simplified.

The operation of the system shown is the same as that of Figure 1, the tuning of the grid circuit and of the feed-back control circuit being the same and of the order of but higher than the operation frequency of the anode circuit and of the oscillator. The feed-back circuit and combined grid circuit reactance reflected over into the oscillator circuit comprising the inductance 27 serves to tune that circuit to the operating frequency $f1$ of the oscillator as before.

It has been found that effective modulation by variation of the input capacitance and resultant variation in the strength of oscillation may be provided by the simplified circuit shown. However, the Q of L1, that is, of the combined inductance of windings 70, 71, 73 and 74 is lower, and the amount of gain and modulation output will be less than when the grid resistor and capacitor are used. This is for the reason that the grid leak and capacitor raise the input impedance of the tube under a steady state condition of oscillation, so that the Q of L1, that is, of the grid circuit inductance, and the associated input circuit will be raised at the resonant frequency.

Furthermore, the grid capacitor and resistor when used, provide a time constant lower in frequency than the lowest modulation frequency desired. Therefore, in this modification of the invention, as well as that shown in the circuit of Figure 1, there is no appreciable modulation frequency on the grid at any time, and the modulation is effected substantially wholly by variation of the oscillation magnitude, with its resultant effect upon the anode current variation.

As referred to hereinbefore, a portion of the circuit of Figure 1 may be made as a detachable unit, including therein the anode circuit and feed-back circuit inductances together with the control circuit cable and modulator device.

This unitary arrangement of that portion of Figure 1 is shown in Figure 4, to which attention is now directed and in which like reference numerals throughout apply to the same parts as in Figure 1. It will be noted that the anode circuit inductance L2 and its closely inductively coupled feed-back inductance coil L3 are included within a self-contained circuit which is independent of the remainder of the oscillator system. The coils L2 and L3 are enclosed within a suitable shielded housing or container indicated by the dotted line enclosure 76.

The terminals 48 and 49 of the feed-back inductance winding L3 are connected with the leads 50 and 51 through the shielded cable 52 which is united with the housing or casing whereby the shield is grounded therethrough.

The housing is provided with suitable plug-in terminal pins for the center-tap terminal 45 of the feed-back winding as indicated at 77, the terminals of the anode inductance 27 as indicated at 78, and ground or casing as indicated at 79. Suitable legends opposite these terminals indicate the corresponding connection points with the circuit of Figure 1. Any suitable terminal arrangement may be provided for plug-in or quick-detachable electrical connection with the oscillator tube circuit. The plug-in unit shown in Figure 4 is readily adaptable for production as an article of manufacture for plugging directly into electronic amplifier apparatus containing the remainder of the oscillator circuit, as in the circuit of Figure 1.

From the foregoing description it will be seen that in accordance with the invention a self-excited, electronic tube oscillator system may be provided with high gain, high fidelity modulation by simplified circuit means providing differential feed-back variation of the input capacitance and response frequency of the grid circuit, thereby to produce an accentuated variation in the strength of oscillations and in the modulation signal output of the oscillator.

This system operates effectively through the medium of a balanced variable impedance feed-back circuit coupled inductively closely to the anode circuit and having a coupling connection from an intermediate point thereon to the grid circuit. Variable impedance modulating means in the feed-back circuit provides feed-back current which varies differentially thereby to provide differential in-phase and counter-phase inductive feed-back to the grid circuit to vary the amplitude of the oscillations and the relative resonant frequencies of the grid and anode circuits.

The system may be provided by a minimum number of low cost circuit elements which may be combined as shown in Figure 3, and which may be assembled in substantially a non-radiating modulated oscillator capable of producing a relatively high gain at the output circuit thereof in response to minute variations of the control element.

Furthermore, because of the effectiveness of the control system, the modulation source or modulation control elements may comprise impedances or reactances of relatively low value and therefore may be of relatively small size and weight as is desirable for phonograph record reproduction, for example: An improved electronic tube oscillator system of the self-excited, modulated type embodying the invention provides a modulation control effect and a modulation voltage or signal output of high fidelity and greatly increased intensity exceeding that of any known modulated oscillator system, and, accordingly, while particularly well adapted for faithful and highly amplified reproduction of phonograph records, has a wide field of adaptability and usefulness in the electronic industry.

What is claimed as new and useful:

1. In a self-excited electronic tube oscillator system having an anode circuit and a grid circuit, the combination of means for tuning the anode circuit to a predetermined fixed frequency of oscillation, and means coupled to the anode circuit and to the grid circuit for differentially varying the feed-back and the input admittance of the grid circuit whereby the tuning response of the grid circuit and the strength of oscillations are varied to effect a variation in the output signal from the anode circuit at a modulation frequency, said last named means comprising a feed-back inductance closely inductively coupled to the anode circuit and having an intermediate terminal connected with the grid circuit, a pair of closely associated control leads connected with the terminals of said feed-back inductance, variable impedance connected between the terminal end of each of said leads and ground for said system and a movable control element responsive to a desired modulation frequency for varying said impedances differentially to provide differential in-phase and counter-phase inductive feed-back of energy to said grid circuit to vary the amplitude of oscillation and the modulation output of said system.

2. In an electronic tube oscillator system, the combination of means providing a high inductance anode circuit, a grid circuit having a tuning inductance therein, means for variably controlling feed-back of energy from the anode circuit to the grid circuit comprising a feed-back inductance having close inductive coupling with and a reflected reactance in said anode circuit for tuning said oscillator system to a predetermined oscillation frequency, means providing an intermediate tap connection on said feed-back inductance for the grid circuit, means providing a variable impedance path between the terminal ends of said feed-back inductance and ground for said system operative to effect differential control of said impedance paths, thereby to provide in-phase and counter-phase feed-back of energy to the grid circuit and a variation in the input capacity of the grid circuit, thereby to vary the strength of oscillations and the anode current proportionally, and means in the output circuit of the oscillator for deriving therefrom the modulation signal component.

3. In an electronic tube oscillator system, the combination of an anode circuit, a grid circuit, means for variably controlling feed-back of energy from the anode circuit to the grid circuit comprising a feed-back inductance having close inductive coupling with and a reflected reactance in said anode circuit for tuning said oscillator system to a predetermined oscillation frequency, means providing a feed-back connection on said inductance for the grid circuit, modulation means providing a variable impedance path between the terminal ends of said feed-back inductance and ground for said system operative to effect differential modulation control of said impedance paths, thereby to provide differential feed-back variation and a variation in the input capacity of the grid circuit, thereby to vary the strength of oscillations and the anode current proportionally, and means in the output circuit of the oscillator for deriving therefrom the modulation signal component.

4. In a self-excited electronic tube oscillator system having an anode circuit and a grid circuit, the combination with means for establishing feed-back for sustained oscillations, of means for varying the feed-back from the anode circuit to the grid circuit in-phase and counter-phase with respect to said first named feed-back and for varying the input capacity of the grid circuit and the tuning response thereof, thereby to vary the magnitude or strength of the oscillations of the oscillator, means coupled to the anode circuit for maintaining the frequency of the oscillations substantially constant while the tuning response of the grid circuit varies, and means for deriving an output modulation signal from the anode circuit.

5. In a self-excited electronic tube oscillation system, modulating means therefor comprising in combination, a grid circuit tuned to resonance at a predetermined frequency, an anode circuit, a feed-back inductance coupled to the grid circuit from an intermediate point thereof and closely inductively coupled to the anode circuit, means providing a feed-back path to ground of the system from each of the terminals of said feed-back inductance, means for differentially varying the impedance of said feed-back paths to provide differential in-phase and counter-phase feed-back of energy to said grid circuit to vary the input admittance thereof and the amplitude of oscillation of said system, and means for deriving a modulation signal output from said anode circuit in response to modulation control of said differential impedance varying means.

6. In a self-excited electronic tube oscillation system, modulating means therefor comprising in combination, a grid circuit tuned to resonance at a predetermined frequency, an anode circuit, a feed-back inductance included in the grid circuit by connection therewith from an intermediate point on the feed-back inductance, said feed-back inductance being closely inductively coupled to the anode circuit, means providing a feed-back path to ground of the system from each of the terminals of said feed-back inductance, means for differentially varying the impedance of said feed-back paths to provide differential in-phase and counter-phase feed-back of energy to said grid circuit to vary the input admittance thereof and the amplitude of oscillation of said system, and means for deriving a modulation signal output from said anode circuit in response to modulation control of said differential impedance varying means.

7. An electronic tube oscillator system comprising in combination a tunable anode circuit, a tunable grid circuit, an output anode impedance connected with said tunable anode circuit, a third tunable circuit comprising a feed-back inductance closely inductively coupled with said anode circuit and having a mid-tap connection coupled to the grid circuit to apply variable feed-back of energy thereto, a pair of control leads connected with the terminals of said feed-back inductance and extending therefrom in closely associated relation to each other providing stray capacity between them for tuning said inductance to resonate the anode circuit by reflected reactance, means providing inversely variable impedance elements between the terminal ends of said control leads and ground for said system, means for adjusting the tuning of said anode and grid circuits whereby the frequency of the grid circuit is of the order of and higher than the frequency of the anode circuit, and means for actuating said variable impedance elements to provide inverse impedance variation thereof to modulate said system.

8. A self-excited electronic tube oscillator system comprising in combination, a tunable anode

circuit and a tunable grid circuit for generating self-oscillations, of a feed-back winding closely inductively coupled to said anode circuit and having a coupling connection from an intermediate point thereon to one side of the grid circuit, means for tuning said feed-back winding whereby the anode circuit is resonated by reflected reactance therein, said means including a control circuit for said winding and a variable impedance element connected with each of the terminal ends of said winding through said control circuit, means for inversely varying said impedance elements to modulate said oscillator system by differentially positive and negative input capacity variation on said grid circuit, thereby to vary the strength of said self oscillations, and means for deriving from said system the modulation signal resulting from said variation.

9. An oscillator system comprising in combination, an electronic tube having an anode, a cathode and a control grid, an untuned anode circuit for said tube, an inductance therein, a grid circuit for said tube responsive to a frequency higher than the response frequency of the anode circuit and of the oscillator and having as tuning elements thereof the reflected grid-to-anode capacity of said tube and a second inductance, a feed-back circuit, a feed-back inductance in said last named circuit coupled with the grid circuit at substantially the inductive center of said inductance and having close inductive coupling with the anode circuit, inductance means including said feed-back inductance providing substantially balanced opposing feed-back paths from said grid circuit coupling to ground of said system, means for variably unbalancing the impedance of said paths to modulate said system, and means providing a modulation signal output circuit for said system.

10. An oscillator system comprising in combination, an electronic tube having an anode, a cathode and a control grid, an untuned anode circuit for said tube, an inductance therein, a grid circuit for said tube responsive to a frequency higher than the response frequency of the anode circuit and of the oscillator and having as tuning elements thereof the reflected grid-to-anode capacity of said tube and a second inductance, a feed-back circuit, a feed-back inductance in said last named circuit coupled with the grid circuit at substantially the inductive center of said inductance and having close inductive coupling with the anode circuit inductance, all of said inductances being substantially equal in inductance value, means including said feed-back inductance providing substantially balanced opposing feed-back paths from said grid circuit coupling to ground of said system, means for variably unbalancing the impedance of said paths to modulate said system, and means providing a modulation signal output circuit for said system.

11. An electronic tube oscillator system comprising in combination, means providing a tunable anode circuit inductance and a tunable grid circuit adapted to be coupled and tuned by the inter-electrodal capacities of an associated electronic oscillator tube, an output anode impedance connected with said tunable anode circuit, a third tunable circuit comprising an inductance winding closely coupled with said anode circuit and having a mid-tap connection thereon coupled to the grid circuit to apply variable current under neutralization thereto, a pair of control leads connected with the terminals of said inductive winding and extending therefrom in closely associated relation to each other providing stray capacity between them for tuning said inductance to resonate the anode circuit by reflected reactance, means providing inversely variable impedance elements between the outer terminal ends of said control leads and ground for said system, means for adjusting the tuning of said anode and grid circuits whereby the frequency of the grid circuit is higher than the frequency of the anode circuit, and means for actuating said variable impedance elements to provide inverse impedance variation thereof and modulation of said system.

12. A self-contained modulator unit for an electronic tube oscillator system comprising in combination, a pair of closely coupled inductance coils, a transmission system having a pair of conductors respectively connected to the end terminals of one of said inductance coils and being adapted for connection at their outer terminal ends to a pair of impedances, said transmission system conductors being relatively immovable with respect to one another throughout the major extent of their length, a conductor connected to an intermediate point of that one of said inductance coils which is connected to the transmission system conductors, said pair of inductance coils and said transmission system conductors being enclosed within an electrically conductive shield and said impedances being respectively electrically connected to said shield, and a plurality of terminals respectively connected to the conductor leading from the midpoint of the inductance coil in circuit with the transmission line conductors, to the opposite terminals of the other inductance coil and to the said shield, said terminals being adapted for respective connection with corresponding elements of an electronic tube oscillator system to be modulated by said modulator unit.

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The following references are of record in the file of this patent:

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Certificate of Correction

Patent No. 2,443,125. June 8, 1948.

PAUL WEATHERS

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Column 1, line 7, for the patent number "2,436,139" read *2,436,129*; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 7th day of September, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.