

Feb. 17, 1948.

P. WEATHERS

2,436,129

OSCILLATOR

Filed Dec. 22, 1945

2 Sheets-Sheet 1

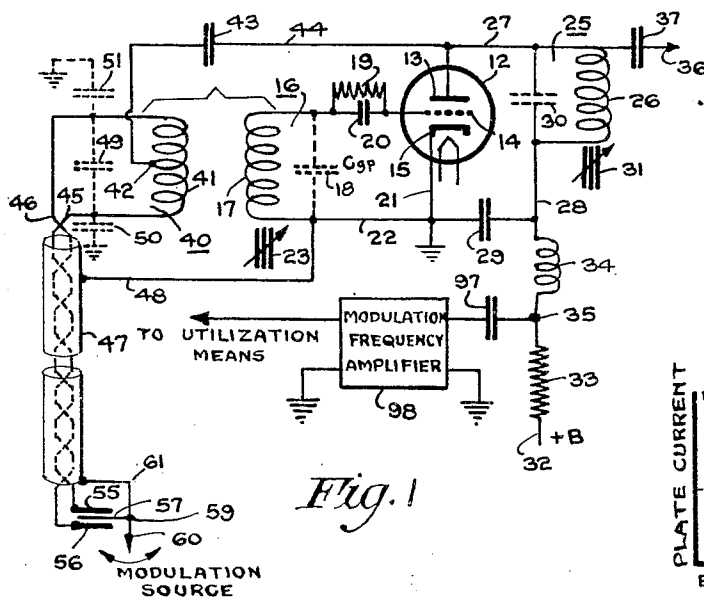


Fig. 1

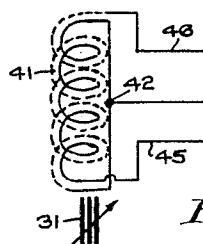


Fig. 2

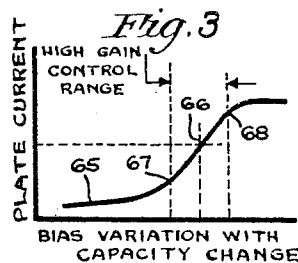


Fig. 3

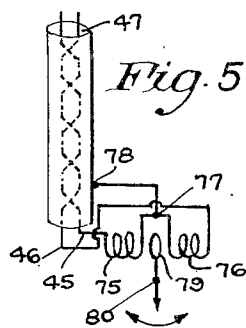


Fig. 5

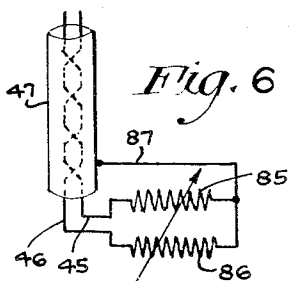


Fig. 6

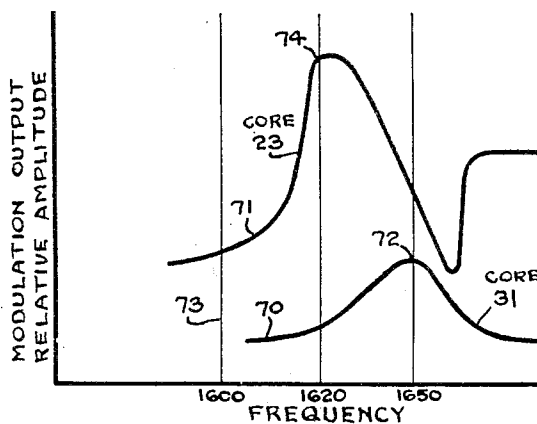


Fig. 4

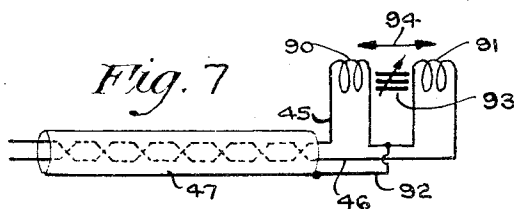


Fig. 7

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**Feb. 17, 1948.**

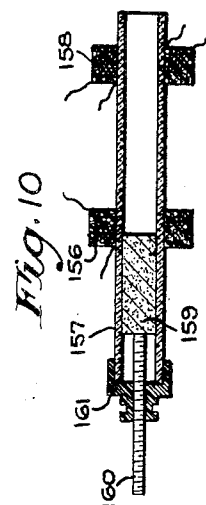
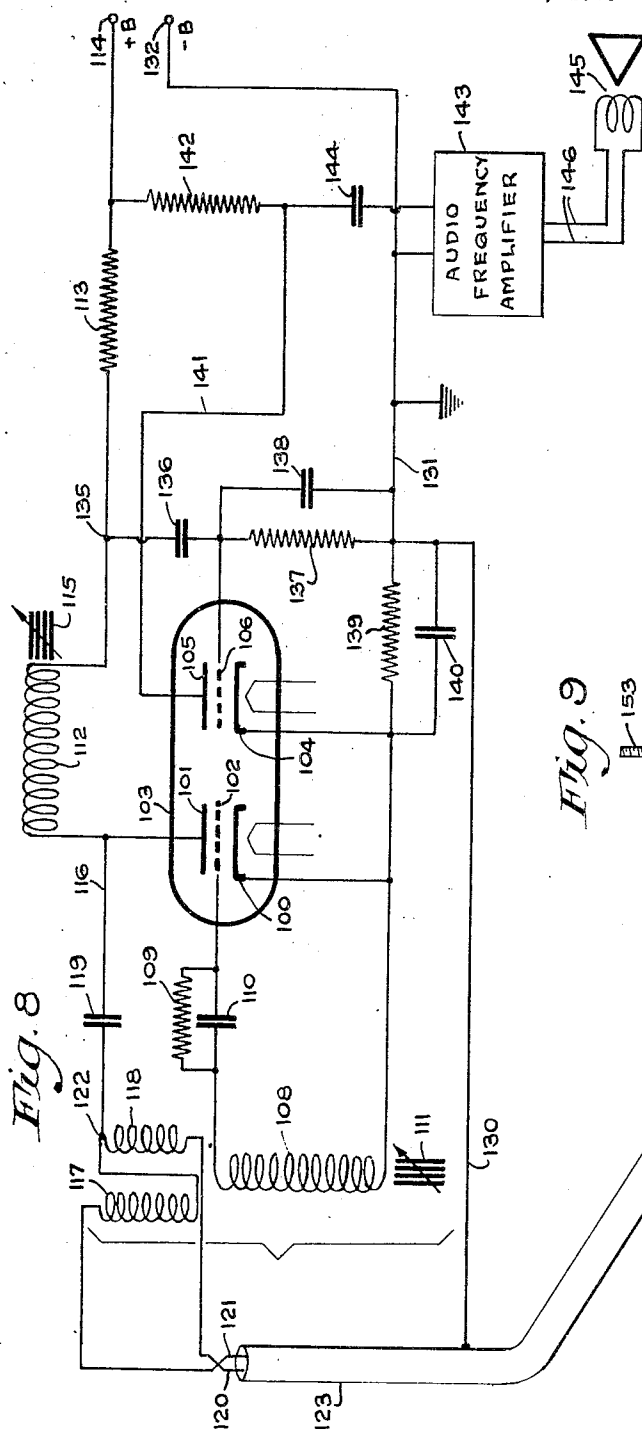
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## OSCILLATOR

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2 Sheets-Sheet 2



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## UNITED STATES PATENT OFFICE

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## OSCILLATOR

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17 Claims. (Cl. 179—171.5)

1

The present invention relates to oscillators of the electronic tube type, and more particularly to self-excited, electronic tube, modulated oscillators, and has for its primary object to provide an improved oscillator of the character referred to, which is responsive to extremely small changes in an electrical characteristic of a control circuit therefor, such as a relatively small capacity, inductance, or resistance variation, occurring at a remote or extended end of said control circuit, to produce a greatly enhanced control or modulation effect on said oscillator and a corresponding relatively large and amplified change in oscillator anode current or output potential.

It is also an object of this invention, to provide an improved method and means for controlling an electronic tube oscillator whereby the anode current or output potential thereof may be varied with a high degree of sensitivity and over a relatively wide range in response to extremely small changes in capacity, inductance or resistance in a control circuit coupled with the oscillator, and whereby the variable capacity, inductance, or resistance referred to may be located at the end of a relatively long extension of the control circuit, such as a transmission line and may, therefore, represent only a relatively small portion of the total overall capacitance, inductance, or resistance of the circuit, without impairing the sensitivity and control range.

It is a still further object of the present invention, to provide an improved oscillator of the self-excited, electronic-tube type which takes advantage of the Miller, or grid-circuit frequency-variation effect, with variation in control grid bias, as described in chapter 7 of "Radiotron Designer's Handbook," third edition, a publication of RCA Manufacturing Co., Inc., Harrison, N. J., in providing further depth and amplitude to the modulation action thereon in response to extremely small or minute variations in an electrical characteristic of a control circuit therefor.

It is a further object of this invention, to provide dual action or push-pull control in the modulation of an electronic-tube oscillator, through a control connection involving a relatively long transmission line and by means of substantially minute variations in capacity, inductance, or resistance at the end thereof.

Because of the permissible extension of the control circuit through a transmission line and the relatively small circuit elements required for effecting a relatively wide control action on the modulation or anode current change, a modulated oscillator circuit embodying the invention

2

is particularly well adapted for use in high fidelity phonograph record reproduction systems.

In accordance with the invention, the modulation source or pick-up may comprise a small, light-weight push-pull variable capacitor mounted on the end of a light-weight tone arm, whereby record wear is reduced to an absolute minimum, and the oscillator and associated circuits may be coupled thereto through a shielded or unshielded transmission line of several feet in length without introducing undesired modulation effects, and without, in any way, limiting the frequency range of response of the pick-up or the amplitude of the controlling effect upon the oscillator and the resulting signal output therefrom.

Furthermore, because of its sensitivity to relatively small electrical controlling effects, an electronic tube oscillator circuit embodying the invention is particularly adapted for use in detecting small variations in the content of flowing fluids and for registering the approach and departure of a moving body with respect to a protected area. Thus, an oscillator circuit embodying the invention may readily be adapted for detecting foreign matter in the flow of gasoline, oil or water, for example, and for the protection of safes, windows, and doors in an alarm system or the like, as well as for phonograph record reproduction, microphone sound pick-up and the like.

In accordance with the invention, two high frequency circuits, tuned to substantially the same frequency, are coupled to permit the transfer of energy from the one to the other, the one or first tuned circuit being located in the anode circuit of an electronic tube oscillator and the other, or second tuned circuit, being coupled, preferably by loose inductance coupling, with the grid circuit of said oscillator and arranged to provide differential feed-back therewith. The grid circuit is tuned to a slightly lower frequency than said first and second circuits and of the same order.

Further, in accordance with the invention, a balanced-to-cathode or ground transmission line or control circuit is connected with the second circuit, in such a manner that it is extremely sensitive to capacity, inductance, or resistance changes at its terminal end and operates to trigger the flow of energy from the first to the second circuit, and thence to the grid circuit of the oscillator by the coupling hereinbefore referred to, thereby to provide by a dynamic feed-back action on the grid circuit, which is amplified by the Miller effect, a greatly enhanced variation in anode current or output potential, and rela-

tively deep modulation effect upon the oscillator in response to variations of said capacity, inductance, or resistance.

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

In the drawings:

Figure 1 is a circuit diagram of electronic tube modulated oscillator embodying the invention in a present preferred form;

Figure 2 is a circuit diagram illustrating the electrical construction of a circuit element of Figure 1;

Figures 3 and 4 are graphs showing curves illustrating certain operating characteristics of the circuit of Figure 1;

Figures 5, 6 and 7 are circuit diagrams showing detail modifications of a portion of the circuit of Figure 1 in accordance with the invention;

Figure 8 is a schematic circuit diagram of electronic tube modulated oscillator and associated amplifier circuits embodying the invention in a practical form for phonograph record reproduction; and

Figures 9 and 10 are cross-sectional views, and substantially full size, of certain of the circuit elements of Figure 8.

Referring to Figure 1, 12 is an electronic oscillator tube of the thermionic type having an anode or plate 13, a control grid 14, and a heated cathode 15. Between the grid and the cathode is connected a tuned grid circuit 16 comprising a variable tuning inductance 17 and shunt tuning capacity indicated at 18, comprising mainly the reflected grid-to-plate capacity,  $C_{gp}$ , of the tube, together with stray capacity and the grid-to-cathode capacity of the tube.

A grid resistor 19 and shunt grid capacitor 20 are connected between the grid and the inductance 17 at the high potential side of the circuit 16. The cathode is connected to ground through a lead 21, and a grid circuit return lead 22 to cathode from the tuning inductance 17, is provided at the low potential side of the tuned circuit 16.

Since the capacity represented at 18 is the sole tuning capacity for the circuit 16, the inductance element at 17 may be made relatively high in inductance value and the tuning adjustment of the circuit 16 may then be accomplished by varying the inductance 17, preferably by movable iron core tuning means as indicated at 23.

A similar tuned circuit 25 is connected between the anode and the cathode. This comprises a variable tuning inductance 26 connected to the anode through an anode circuit lead 27 and connected to the cathode and ground through a lead 28 and a by-pass capacitor 29. The shunt tuning capacity for the circuit 25 is provided by the combined plate-to-cathode and the plate-to-grid capacities of the tube, indicated at 30.

The tuned anode and grid circuits are of the high inductance type, adapted for tuning to a relatively sharp resonance peak. As in the case of the grid circuit, the anode circuit is tuned to desired resonance by varying the inductance 26, preferably, as indicated, by means of a movable iron tuning core indicated at 31.

Anode current is supplied to the oscillator from a positive supply lead indicated at 32, through an output coupling impedance provided by a resistor 33, and a radio frequency choke coil 34 connected with the lead 28. A low or audio fre-

quency signal output terminal 35 is provided between the choke coil 34 and the output resistor 33 in connection with the high potential end of the latter. This is for the purpose of deriving signal output from the impedance 33 as the result of anode current variations at the modulation frequency. Other output connection may be made with the anode circuit to derive therefrom any desired electrical output effect. For example, the tuned anode circuit 25 may be coupled to an output circuit indicated at 36 through a coupling capacitor 37 to provide modulated radio frequency signals for further amplification, detection and utilization as in any conventional radio receiver circuit.

When the grid and anode circuits 16 and 25 are tuned to resonance by adjustment of the respective cores 23 and 31, the tube 12 will oscillate because of energy feed-back through the grid-to-plate capacity,  $C_{gp}$ , from the circuit 25 to the circuit 16. When the tube oscillates, the anode current flow through the resistor 33 decreases because of an increase in negative bias on the oscillator grid 14 established by the grid current flow through the grid resistor 19, until a steady state of oscillation is established. The oscillator is thus self-excited and tends to oscillate at a fixed frequency until the feed-back or energy applied to the grid circuit is varied.

Differential variation of feed-back for modulation or other control of the anode current and the oscillator signal output, is provided through a third tuned circuit 40, comprising an inductance winding 41 having a center tap 42 connected or coupled with the anode 13 through a coupling capacitor 43 and a feed-back circuit 44. The terminal ends of the inductance winding are connected to a transmission line forming part of a control circuit and comprising a pair of closely associated insulated leads 45 and 46, preferably twisted together and inclosed within a conducting shield 47, which is connected as indicated at 48 to the cathode return lead 22 of the oscillator grid circuit 16 and ground for the system.

With this arrangement, it will be seen that the substantially fixed capacity existing between the twisted leads 45 and 46 is effectively connected in shunt across the tuning inductance 41 as indicated at 49, thereby providing a shunt tuning capacity for the circuit 40. When, furthermore, a shield is provided for the transmission line, additional tuning capacity effectively across the inductance 41 is provided by the stray capacity between each of the twisted leads of the cable and the shield 47, the components of which are indicated at 50 and 51 respectively. The total tuning capacity across the inductance 41, therefore, is that indicated at 49, plus the capacities indicated at 50 and 51 in series.

The capacities 50 and 51 are also connected through the feed-back control circuit effectively in parallel relation to the oscillator tuning inductance 26 since the two halves of the winding 41 are differentially connected in the feed-back path and inductively neutralize each other, and therefore, as the length of the cable is increased the capacities 50 and 51 likewise increase in value and tend to tune the anode circuit to a lower frequency. At the same time, the effective capacity 49 between the leads 45 and 46 of the cable is increased, thereby correspondingly lowering the tuning response of the feed-back control circuit 40, and causing the two circuits to remain substantially in resonance one with the other regardless of the extension of the control

cable within normal limits. In any case, however, the tuning change for any length of the cable as required, which may tend to provide an appreciable frequency difference, may be corrected by adjustment of the tuning of the inductance 26 in the anode circuit by means of the tuning core 31.

Since the cable comprises a closely twisted or associated pair, the value of the capacity 49 is substantially fixed, while shifting of the cable in the shield or movement with respect to the system ground and cathode connection as by movement or vibration of the cable and shield, changes both of the capacity values indicated at 50 and 51 substantially equally. Therefore, as a result, the overall change in capacity balance is effectively zero and no undesired modulation or noise effect is produced upon the system, as will hereinafter be described.

The terminal end of the transmission line is connected to a suitable variable control or modulation source providing inversely variable, and preferably normally balanced, impedance paths to ground or cathode for the control circuit leads 45 and 46. In the present example, the modulation source is provided by a push-pull variable capacitor having fixed plates 55 and 56 connected respectively with the terminal ends of the leads 46 and 45, and a plate or electrode 57 located between the fixed plates and pivoted as at 59 for example, for oscillation between said plates to increase the air or dielectric gap on one side and correspondingly decrease the air or dielectric gap on the other in response to movement imparted thereto by a phonograph record pick-up stylus 60, representing any suitable means for imparting push-pull controlling action to the balanced capacitor arrangement. The variable impedance path to ground or oscillator cathode from each electrode 55 and 56 is completed by connecting the movable plate 57 as at the pivot 59, to ground through a lead 61 connected with the shield 47.

Referring to Figure 2, along with Figure 1, a present preferred construction for the tapped coil or inductance 41 is shown, in which the two sections or portions on either side of the mid-tap 42 are inductively equal and comprise parallel conductors preferably wound in a bi-filar or double lead arrangement simultaneously and connected in series aiding as indicated. The total overall inductance of the winding 41 is made essentially equal to that of the inductance 26 in the anode circuit. The operational effect is to provide a balanced feed-back coil or inductance which may be tuned overall to the same frequency as the anode circuit. The tap 42 is thus at the electrical or inductive center of the winding 41, and therefore, a current introduced at the tap 42 will flow in opposite directions through the winding 41 to the leads 45 and 46, and provide opposing feed-back or inductive coupling effects in the circuit 40 and upon any associated inductive winding such as the inductance 17 in the grid circuit.

The two portions of the inductance 41 preferably are twisted together before winding to further insure a balanced feed-back effect with the same current flow in each portion and essentially the same stray capacity coupling between each portion and the inductance 17 of the grid circuit. Loose coupling is preferably provided in order that the stray coupling may be reduced to a minimum and to permit the grid circuit to vary in frequency independently of the frequency

of the circuit 40 and of the circuit 25, as will hereinafter be described.

With the balanced feed-back arrangement described, it will be seen that as the impedance to cathode or ground return circuit of the system at the terminal ends of the transmission line is varied by movement of the balanced capacitor armature 57 between the fixed electrodes 55 and 56, feed-back from the anode circuit 25 to the grid circuit 16 will be increased and decreased correspondingly by reason of the differentially derived currents reducing oscillation amplitude when unbalanced in one direction and increasing oscillation amplitude when unbalanced in the opposite direction through the winding 41, thereby increasing and decreasing the effective feed-back to the grid circuit and the amplitude or intensity of the oscillation voltage therein. The corresponding variation in the bias voltage across the grid resistor 19, and in the anode current flow through the output resistor 33 in proportion thereto, is greatly amplified by reason of the push-pull feed-back action and the Miller effect as will be seen from a further consideration of the circuit of Figure 1 and the graphs shown in Figures 3 and 4.

Referring to Figure 3, the relation between grid bias voltage variation with capacity change at 55-56-57 and resulting anode or plate current change is illustrated by the curve 65. Normally, the adjusted value of grid resistor 19, the feed-back through the grid-to-plate capacity and the resulting grid bias is such that the anode current is adjusted to a value represented at the point 66 with steady-state oscillation at a fixed frequency.

The differential feed-back through the inductance 41 under control of the inversely variable or push-pull impedance at 55-56-57 is such that the grid bias varies to effect an anode current variation between limits indicated at 67 and 68, the latter being just below the upper knee of the plate-current grid-bias curve in order that the anode current variations may be along a linear portion of the curve and follow without distortion the modulation variations at the modulation source.

The tube thus operates in a high gain control range, with the anode current at a normal minimum consistent with permitting a desired variation in anode current without distortion. Thus, the oscillator may provide weak oscillations without losing effectiveness and without radiating energy which would cause objectionable interference with other electronic apparatus in the immediate vicinity.

Referring now to the arrangement for utilizing the Miller effect in the grid circuit and resulting bias variation to provide a wider variation in anode current and modulation output than would otherwise be possible with the push-pull feed-back control, it will be seen that since the grid-to-plate capacitance,  $C_{gp}$ , is variably amplified by variations in the bias voltage of the oscillator, and in effect shunts the grid inductance at 18, as previously described, it is obvious that the resonance of the grid circuit 16 will drop in frequency with a decrease in the strength of oscillations, and conversely will rise in frequency with an increase in the strength of oscillations as provided by the modulation feed-back through the coil 41 in response to variations in the terminal impedance of the transmission line.

It has been found that to obtain the aiding action of the Miller effect, the grid circuit must be

tuned to a mean frequency of the order of and slightly below the resonance frequency of the anode circuit, that is, the anode circuit 25 is tuned to a higher frequency than the grid circuit 16, so that as the strength of oscillation increases in the grid circuit 16, the resonance frequency of the latter circuit rises and more closely approaches that of circuit 25, thus increasing the strength of oscillations further, by reason of its closer approach to resonance with the circuit 25, until a condition of equilibrium is reached. Conversely, this action aids in decreasing the strength of oscillations when the feed-back through coil 41 is negative and opposes feed-back grid-to-plate capacitance  $C_{gp}$ . This action will further be described hereinafter when considering the operation of the system.

With the foregoing arrangement and frequency relation between the tuned anode and grid circuits, it will be seen that as the grid bias varies in response to feed-back, the Miller effect may be utilized to produce wide variation of the capacity indicated at 18 and, therefore, greatly increases the feed-back effect and provides a greater degree of modulation or control of the oscillator than would otherwise be possible and a higher signal output or anode current variation.

As a further means for enhancing the modulation or control of the system described, consideration will now be given to the tuning of the circuit 40, which is determined by the inductance at 41 and the shunt capacities indicated at 49, 50 and 51. These capacities are determined by the length of the cable, the tightness of the twist of the two control leads 45 and 46, and the spacing between the leads and the outer shield, which is determined by the thickness of the outer insulation used between the leads and the cable.

As hereinbefore referred to, variations of the twisted pair within the cable with regard to spacing from the shield or other movement with respect to ground or cathode return connection has substantially no effect upon the frequency of the circuit 40, or upon the balanced feed-back normally provided by the inductance 41, since both the control wires are tightly twisted and in movement toward or away from the shield or other grounded object, provide a simultaneous variation of both the capacity indicated at 50 and the capacity indicated at 51 in the same sense, so that no unbalance of the feed-back is caused thereby.

Further, since the capacities represented at 50—51 are relatively small compared to the capacity at 49 between the twisted pair, even if the leads 45 and 46 became slightly separated, slight change in frequency would result because of movement of the cable within the shield or with respect to ground or cathode return circuit.

Therefore, it will be seen that the cable may be extended to a distance of several feet or to a limit in the value of the capacity at 49 which is required to resonate the coil 41 within a desired frequency range, this range being determined by the desired operating frequency of the oscillator.

Since the transmission line is at all times balanced to ground thereby providing a balanced positive and negative feed-back of minimum strength through the feed-back winding 41, full modulation control of great range may be realized at the terminal end of the transmission line by the use of a relatively small capacity change, such as provided by a movable metallic reed or

spring plate at 57 a small fraction of an inch in width when vibrated almost imperceptibly between two similar narrow fixed plates at 55 and 56 relatively widely spaced therefrom as will hereinafter be described.

To further provide that such small capacity or reactance change may control a large and effective feed-back current, the circuit 25 is tuned substantially to resonance with the circuit 40. This is accomplished by adjustment of the variable core 31 in the present example. The exchange of energy from the circuit 25 to the circuit 40 upon slight movement of the controlling element at the modulation source is thereby caused to be instantaneous and dynamic in effect, because of the resonance condition existing between the two circuits. Furthermore, it will be seen as the flow of current through one winding portion increases, the flow through the other winding portion decreases proportionately, thereby further enhancing the control action or modulation range by push-pull action.

To illustrate the enhanced overall control effect, attention is now directed to Figure 4 in which the signal output at the terminal 35 in response to tuning of the circuits 25 and 16 is shown by curves 70 and 71, respectively, plotted between frequency and the modulation signal amplitude at the terminal 35. As the core 31 is varied to bring the anode circuit 25 into resonance with the control circuit 40 at a predetermined frequency, such as 1650 kc. for example, the output amplitude increases along the curve 70. In operation, the core 31 is adjusted until the two circuits resonate to provide maximum output as indicated at the point 72 on the curve 70, with the grid circuit 16 detuned, for example, to 1600 kc., as established on the graph by the line 73. The grid circuit 16 is then tuned to approach the frequency of the anode circuit 25 and at a certain frequency, such as 1620 kc. as indicated at the point 74 on the curve 71, a maximum modulation signal output is obtained at the terminal 35.

The tuning of the grid circuit may now vary about the mean frequency of 1620 kc. in response to variations in the grid to plate capacity,  $C_{gp}$ , as hereinbefore described, while remaining below the frequency of the anode and feed-back controlling circuits 25 and 40 respectively, and thereby permitting full advantage of the Miller effect to be taken in providing enhanced modulation control of the oscillator. As hereinbefore pointed out, the grid circuit 16 readily may vary in frequency because of the loose coupling provided between the windings 17 and 41.

The operation of the system is as follows: With the oscillator energized, the anode circuit 25 is tuned to resonance with the control circuit 40, and the grid circuit 16 is tuned to resonance at a lower frequency of the same order, for maximum response as hereinbefore described. Feed-back of energy from the anode circuit through the grid-to-anode capacity maintains the grid circuit in a steady state of oscillation at that frequency, and grid current therefrom flowing through the resistor 19 causes the grid to assume substantially a fixed negative bias, which in turn reduces the average anode current flowing through the output coupling impedance 33 to a constant normal value, as indicated at 66 in Figure 3. With substantially no variation in average anode current, the modulation signal output at the terminal 35 is zero. Radio frequency energy from the tuned anode circuit is

prevented from appearing at the output terminal by the bypass capacitor 29 and the choke coil 34.

Feed-back current at the frequency of the tuned anode circuit 25 flows from the anode connection 27 through the coupling connection 44—43 to the similarly tuned control circuit 40, and divides at the terminal 42 to flow in part upwardly and equally in part downwardly, as viewed in the drawing, to the terminal ends of the inductance 41 and the control leads 45 and 46, and thence through the cable to the capacitor plates or electrodes 55 and 56, respectively, of the modulation or control source. The alternating feed-back currents from each electrode 55 and 56 flow to the center electrode 57 and unite to flow back to the ground for the system and the anode circuit, through a common path which may be traced from the pivot 59 through the lead 61 to the shield 47, thence through the connection leads 48 and 22 to the cathode and chassis ground, and thence through the bypass capacitor 29 to the anode circuit by way of the lead 28. The feed-back currents thus flow through the winding 41 in opposition and when equal, neutralize the feed-back action of the anode current as appears from the following consideration.

Assuming that the flow of feed-back current in the inductance winding 41, upwardly as viewed in the drawing from the terminal 42, excites the circuit 40 to provide positive feed-back of energy to the grid circuit 16 through the loose inductive coupling, the resulting voltage induced in the circuit 16 would be in phase with the voltage induced by the normal feed-back through the grid-to-plate capacity, thereby increasing the effective circuit voltage and grid current through the grid resistor 19.

Likewise, assuming that the flow of feed-back current in the inductance winding 41, downwardly as viewed in the drawing from the terminal 42, excites the circuit 40 to provide the opposite or negative feed-back of energy to the grid circuit, the resulting voltage induced therein would be in counter phase with the voltage induced by the normal feed-back, thereby decreasing the effective circuit voltage and grid current through the grid resistor.

Assuming a balanced feed-back condition with substantially equal feed-back current flow through each half of the winding 41 from the terminal 42, by reason of substantially balanced impedance paths 55—57 and 56—57 in the control circuit 45—46 connected therewith, as when the capacitor plate 57 is substantially centered between the fixed plates 55 and 56, it will be seen from the foregoing considerations, that the excitation effect upon the circuit 40 and feed-back to the circuit 16 will be substantially zero, resulting in no change in grid bias and anode current.

Assuming now a condition of unbalance of the feed-back paths as the capacitor plate 57 is moved toward the plate 56 and away from the plate 55, the impedance or reactance of the balanced paths are varied inversely. The feed-back current flow through the winding 41 from the terminal 42 to the lead 46 will increase and the feed-back current flow through the winding 41 from the terminal 42 to the lead 45 will decrease correspondingly. Under the conditions assumed, this results in a differential or preponderance of current flow in the upper half of the winding 41 and a differential excitation of the circuit 40 to produce positive feed-back on the grid circuit and a corresponding increase in negative grid bias

and decrease in anode current. It will be appreciated that the effectiveness of this change is enhanced by the inverse control or push-pull action, that is, by the simultaneous increase of feed-back current through the one half of the winding 41 and the corresponding decrease in feed-back current through the other half in response to the push-pull variation of impedance at the end of the control circuit.

The change is further amplified by the Miller effect. As the bias potential becomes more negative, the gain of the tube is reduced and the reflected grid-to-plate capacity,  $C_{gp}$ , which is multiplied by the tube gain and appears effectively at 18, is reduced in value, causing the grid circuit 16 to tune to a higher frequency more nearly approaching that of the anode and control circuits. This causes the grid circuit to become more responsive to feed-back at the anode circuit frequency and additional circuit voltage and increased negative bias results, thereby providing a further reduction in anode current, which continues in accordance with the process outlined above until a steady state of oscillation once more obtains for the new condition of adjustment of the control circuit.

Furthermore, the exchange of feed-back energy from the circuit 25 to the circuit 40, and thence inductively to the grid circuit 16 in response to change, however slight, in the balance or static condition of the control circuit at the modulation or control source, is caused to be instantaneous and dynamic in effect, as referred to hereinbefore, by reason of the condition of resonance existing between the tuned anode circuit and the tuned control circuit.

Assuming a condition of unbalance of the feed-back paths in the opposite direction, as the capacitor plate 57 is moved away from the plate 56 and toward the plate 55, the feed-back current flow in the upper or positive feed-back portion of the winding 41 is decreased and correspondingly increased in the lower or negative feed-back portion thereof by reason of the inverse change in impedance in the two branches of the control circuit. The differential feed-back results in a decrease in the amplitude of the oscillations in the grid circuit and a reduction in the grid bias provided at 19. The average anode current is increased correspondingly, the gain or amplification factor of the tube is increased, and the grid circuit frequency is lowered by the corresponding increase in the reflected capacity  $C_{gp}$  at 18, thereby rendering the grid circuit less responsive to feed-back from the anode circuit and further reducing the negative grid bias until a steady state of oscillation once more obtains for the new condition of adjustment of the control circuit.

The anode current variations thus are intensified and follow the variations in grid bias provided by the variable dynamic feed-back through the tuned circuit 40, which, as has been shown, may be controlled by inversely varying the impedance of the two branches of the control circuit even minutely or to a relatively fine degree. In the case of audio frequency modulation provided by the pick-up or control device, it will be seen that the grid bias voltage is derived by grid circuit rectification. The grid potential thus varies at the audio frequency rate and the amplified audio frequency signal is reproduced by the corresponding anode current variation in the output impedance 33. The amplified audio frequency

signal appears at the output terminal as a voltage variation across the output impedance 33.

It will further be seen that the radio frequency energy of the oscillator is amplitude modulated and may be derived from any part of the oscillator circuit as at the output lead 36 and utilized in any desired manner as by conventional amplification and demodulation as hereinbefore noted.

Referring now to Figures 5, 6 and 7 in turn, modifications of the modulation source of Figure 1 are shown in circuit between the control leads 45 and 46 and ground.

In Figure 5, the leads 45 and 46 are connected respectively to small spaced co-axial inductance windings 75 and 76 in series, with a center tap 77 connected to the cable 47 and ground, as indicated at 78. A small short-circuited conducting ring 79 is arranged to move on a pivot 80 between the windings in response to modulating movement of a stylus or other actuating element 81. As the ring 79 moves, the inductive balance of the windings is changed inversely to permit a flow of instantaneously preponderantly positive or negative feed-back through the winding 41 thereby providing amplified modulation of the oscillator and wide variation of the anode current resulting from the additional accelerating effects as hereinbefore described.

In Figure 6, two equal resistance elements 85 and 86 are provided in connection with the leads 45 and 46 and with a common return path to the shield 47 and ground through a lead 87. As the resistance elements are varied in a manner to increase the one and decrease the other correspondingly in impedance value, the feed-back paths are thereby unbalanced and modulation control results as before described. It has been found that a relatively low resistance of 5000 ohms is satisfactory for this purpose in each branch of the control circuit.

In Figure 7, a circuit similar to that of Figure 5 is shown, in which two small coaxial inductance coils 90 and 91 are connected in series aiding between the leads 45 and 46 and at their mid-point to the cable 47 and ground through a lead 92. The inductive unbalance is effected by a body or particle of matter indicated at 93 which is movable between the coils axially relatively thereto, as a core, by any suitable means for effecting modulation, for example, in the same manner as the ring 79 in the embodiment shown in Figure 5 or as a particle of foreign matter moving in either direction, as indicated by the arrowed line 94, in any carrying medium (not shown).

Thus, the modulation source provided in connection with the extended transmission line or control circuit may assume various forms for the utilization of push-pull or inversely variable impedance or reactance control elements as may be required in the various applications to which the invention is adapted.

Referring again particularly to Figure 1, the modulation output available at the terminal 35 may be utilized in any suitable manner and preferably is taken to any suitable utilization means not shown, through a coupling capacitor 97 connected between the output terminal 35 for the output impedance 33 and a modulation frequency amplifier 98 representing any suitable amplifier means for increasing the modulation output energy to a suitable value for utilization.

From the foregoing description, it will be seen that in an oscillator circuit embodying the invention, the dynamic control provided by the tuned circuits 25 and 40, in conjunction with the Miller

effect upon the frequency variation of the grid circuit, the push-pull action of the feed-back control circuit 40 and of the variable reactance or impedance element at the end of the transmission line provide a maximum high degree of sensitivity in response to slight movement of the modulating or control element of the system.

Referring now to Figure 8, a phonograph record reproduction system is arranged in accordance with the invention, to include a cathode 100, an anode 101 and a control grid 102 for an electronic tube oscillator in the same envelope 103 with modulation signal or audio frequency amplifier tube elements comprising a second cathode 104, a second anode 105, and a second control grid 106, thereby economizing on the number of tubes employed. In the present example, the tube 103 may be of the type known on the commercial market as an 6SC7 tube or dual triode of the indirectly heated cathode type as indicated.

A variable tuning inductance 108 is connected between the control grid 102 and the cathode 100 of the oscillator portion of the tube, and the grid circuit thus formed is provided with a grid resistor 109 and a grid capacitor 110 connected between the grid 102 and the inductance 108. As indicated in the drawing, the inductance 109 is variably tunable by a movable tuning core of ferro magnetic or other suitable material indicated at 111, in conjunction mainly with the reflected shunt capacity of the tube elements 101 and 102 or  $C_{gp}$  as in the circuit of Figure 1.

The anode circuit is likewise tunable by a variable inductance 112 and the tube capacities effectively in shunt therewith. The inductance is connected between the anode 101 and a signal output resistor 113, which in turn, is connected with a source of positive anode potential indicated at 114. The tuning inductance 112 is variably tunable as in preceding example, by means of a movable core of ferro magnetic or other suitable material as indicated at 115.

In operation, as in the preceding embodiment of the invention, the grid circuit is tuned to a slightly lower frequency than the anode circuit and a steady state of oscillation is established by feed-back through the grid-to-plate capacity,  $C_{gp}$  and adjustment of the grid resistor 109.

Modulation feed-back energy is derived from the tuned anode circuit by a feed-back connection 116 with the anode and is applied to a feed-back controlling or modulating inductance, comprising two windings 117 and 118, through a coupling capacitor 119. The windings 117 and 118 provide balanced sections of a single inductance as indicated and as described in connection with Figure 2, to provide a balanced feed-back inductance which is tunable by the distributed capacity of a transmission line comprising control circuit leads 120 and 121 connected therewith as indicated, the feed-back connection from the anode circuit being applied to a center tap connection 122 thereon.

The transmission line preferably is contained in a conducting shield indicated at 123 and extends to a pick-up device comprising two fixed substantial widely separated electrodes 124 and 125 between which is mounted a flexible laterally movable electrode 126 carrying a stylus 127 at its free outer end. The inner terminal ends of the electrodes are mounted in a block of suitable insulating material 128 and the movable electrode is connected to the shield and ground through a connection indicated at 129. Ground

connection for the shield is provided through a lead indicated at 130, which is connected with a ground lead 131 of the oscillator and amplifier circuit, terminating in a negative anode supply terminal indicated at 132.

Modulation of the oscillator in sensitive response to the slightest movement of the stylus 127 is effected through self-excitation of the oscillator and dynamic control of feed-back from the anode circuit to the grid circuit through the inductance comprising the sections 117 and 118 loosely coupled to the grid circuit inductance 108, in conjunction with the Miller effect upon the frequency variation or modulation of the grid circuit, and the push-pull inversely variable reactance action of the control circuit.

The modulation or audio frequency output is derived across the grid resistor 109 shunted by the grid or filter capacitor 110 and appears in amplified form across the output resistor 113 at the output terminal indicated at 135. In the present example, the signal output is applied to the amplifier control grid 106 through an audio frequency coupling capacitor 136 across the impedance of a grid resistor 137 connected to the ground lead 131. The grid resistor is provided with a suitable radio frequency by-pass capacitor 138.

The amplifier portion of the dual triode is self-biased by means of a cathode resistor 139 connected between the cathodes 100 and 104 and the ground lead 131. The cathode bias resistor is provided with a suitable audio frequency by-pass capacitor indicated at 140.

The output anode 105 of the amplifier portion of the tube 103 is connected by a lead 141 to the positive supply terminal 114 through an output coupling resistor indicated at 142, across the impedance of which the amplified audio frequency output is taken and applied to any additional audio frequency or power amplifier, as indicated at 143, through a coupling capacitor 144. The amplifier 143 is, in turn, connected to a sound reproduction device or loudspeaker, indicated at 145, through output leads indicated at 146.

In a practical embodiment of the invention for phonograph record reproduction, as shown in Figure 8, utilizing a tube of the character referred to, having an amplification factor of substantially 70 for each portion thereof and a grid-to-plate capacity of substantially 2.4 mmfd., the grid resistor at 109 was found to provide most satisfactory operation when adjusted to substantially 10,000 ohms in value with a grid capacitor of .0002 mfd. capacity at 110, although a value as high as 1.0 megohm could be used at 109 with satisfactory results. The feed-back capacitor 119 and the by-pass capacitor 138 each may have a value of .0002 mfd., with an amplifier grid resistor of .5 megohms at 137. The coupling resistors at 113 and 142 may have any suitable value, such as 1,000,000 ohms, and the coupling capacitors at 136 and 144 may each have a value of .01 mfd.

The operating frequency in the circuit under consideration was of the order of 1600 kc. which proved to be satisfactory. The anode circuit was tuned to the frequency of the coupling or control circuit or 1650 kc., while the grid circuit was tuned to a mean frequency of substantially 1620 kc.

In the embodiment of the invention shown in Figure 8, the grid and anode inductance elements 108 and 112 each may comprise substantially 144 inches of litz wire form wound on a

$\frac{3}{8}$ " diameter insulating tube, while the control inductance 117-118 may comprise two parallel litz wires each substantially 72" in length, twisted together and form wound simultaneously on the same size form as the grid and anode inductances, as shown substantially full-size in Figures 9 and 10, to which attention is directed along with Figure 8.

In Figure 9, the anode coil or inductance is shown at 150 on a form 151, at one end of which is mounted a metallic cap 152. The cap carries a threaded adjustment screw 153 connected at its inner end with a tuning core 154 of suitable ferro-magnetic material such as powdered iron mixed with an insulating binder. Tuning or variation of the inductance 150 is provided by movement of the core axially with respect thereto as is well understood.

Referring to Figure 10, the grid inductance is provided by a form wound coil 156 mounted on an insulating tube 157 with the modulation control inductance also provided by a similar form wound coil 158 substantially widely spaced from the grid coil to provide loose coupling for reasons hereinbefore pointed out.

Tuning of the grid coil 156 is effected by means of an adjustable ferro-magnetic tuning plug or core 159 adjustable by means of a screw 160 mounted in a threaded cap 161 on the grid coil end of the supporting tube 157.

Referring again more particularly to Figure 8, the pick-up device comprising the electrodes 124, 125 and 126 is preferably constructed substantially as indicated, with a relatively wide outward spread of the fixed electrodes and is represented diagrammatically on a greatly enlarged scale in order to illustrate the principle of operation.

From an inspection of the illustration, it will be seen that the fixed electrodes 124 and 125 are curved outwardly at their free ends to provide a wide separation between them and the flexible center electrode 128. The extreme excursions of the center electrode are indicated in dotted lines at 165 and 166. Thus, at the extreme limits of its movement, it will be noted that the center electrode is in spaced parallel relation to the fixed electrode which it approaches. With this arrangement, the movable electrode moves in a relatively weak electrostatic field between the fixed electrodes and provides a high degree of fidelity in the reproduction of sound from a record. Furthermore, operation of the movable electrode from a neutral position slightly displaced toward either of the fixed electrodes has no appreciable effect upon the fidelity and uniformity of the signal output from the oscillator.

From the foregoing description, it will be seen that a phonograph record reproduction system in accordance with the invention, may be provided by a minimum number of low-cost circuit elements which may be assembled in substantially a non-radiating 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 pick-up device or control element may comprise an impedance or reactance of relatively low value and may, therefore, be of small size and weigh merely a fraction of an ounce on a record surface when in use, thereby providing minimum wear and minimum pick-up of surface noise in operation.

While the invention has been shown and described in several of its present preferred embodiments, it should be understood that it is not limited thereto, but may be carried out in other forms and for other purposes including those hereinbefore referred to.

What is claimed as new and useful is:

1. In an electronic tube oscillator system, means providing a tuned anode circuit responsive to a predetermined frequency, means providing a tuned grid circuit responsive to a frequency of the order of and slightly lower than the first named frequency and having as a tuning element thereof the reflected grid-to-anode capacity of said tube, a third tuned circuit responsive to the frequency of the anode circuit having an inductance element coupled with the anode circuit at substantially the electrical center of said element and providing feed-back coupling with the grid circuit, means including said inductance element providing substantially balanced opposing feed-back paths from said anode circuit to the ground of said system, means for varying the impedance of said paths to modulate said oscillator system, and means providing a modulation signal output circuit connected with said anode circuit.

2. An electronic tube oscillator system comprising in combination, means providing a tunable anode circuit and a tunable grid circuit adapted to be capacitively coupled and tuned by the inter-electrode capacities of an associated electronic oscillator tube, means connected with said grid circuit for providing a grid biasing potential for said tube in response to oscillations in said circuit, an output anode impedance connected with said tunable anode circuit, a third tunable circuit comprising an inductance winding loosely coupled with said grid circuit and having a mid-tap connection thereon coupled to the anode circuit to receive feed-back current therefrom, 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 resonance with the anode circuit, 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 anode circuit is of the order of and higher than the frequency of the grid circuit, and means for actuating said variable impedance elements to provide inverse impedance variation thereof and modulation of said system.

3. An electronic tube oscillator system comprising in combination, means providing a tunable anode circuit and a tunable grid circuit adapted to be capacitively coupled and tuned by the inter-electrode capacities of an associated electronic oscillator tube, means connected with said grid circuit for providing a grid biasing potential in response to oscillations in said circuit, an output anode impedance connected with said tunable anode circuit, a third tunable circuit comprising an inductance winding loosely coupled with said grid circuit and having an electrical mid-tap connection thereon coupled to the anode circuit to receive feed-back current therefrom, a pair of control leads connected with the terminals of said inductive winding and extending therefrom in closely associated substantially parallel relation to each other providing stray capacity between them for effectively tuning said inductance to resonance with the anode circuit, means

providing a common ground circuit return path to the grid circuit and anode circuit for said system, means providing an inversely variable impedance element between said last named circuit means and each of said control leads, means for adjusting tuning of said anode and grid circuits whereby the anode circuit is of the order of and slightly higher than the frequency of the grid circuit, and means for actuating said variable impedance means to provide inverse impedance variation thereof and differential variation of feed-back through said inductance winding.

4. In an electronic tube control apparatus, the combination of a tuning inductance adapted to provide with reflected anode-to-grid capacity effectively in parallel therewith a tunable grid circuit responsive to a predetermined oscillation frequency, a resistance element in said circuit for establishing a variable grid biasing potential in response to variations in the amplitude of oscillations in said grid circuit, a second tuning inductance adapted to provide with the inter-electrode tube capacities effectively in parallel therewith a tuned anode circuit responsive to an oscillation frequency of the order of and slightly higher than that of the grid circuit, a signal output circuit coupled with the anode circuit, a tuned feed-back control circuit having an inductive winding providing feed-back coupling between the anode circuit and the grid circuit, and means for conveying feed-back current from the anode circuit through said winding differentially to provide differential in-phase and counter-phase inductive feed-back of energy to said grid circuit to vary the amplitude of oscillations therein.

5. In an electronic tube control apparatus, the combination of a tuning inductance adapted to provide with reflected anode-to-grid capacity effectively in parallel therewith a tunable grid circuit responsive to a predetermined oscillation frequency, a resistance element in said circuit for establishing a variable grid biasing potential in response to variations in the amplitude of oscillations in said grid circuit, a second tuning inductance adapted to provide with the inter-electrode tube capacities effectively in parallel therewith a tuned anode circuit responsive to an oscillation frequency of the order of and slightly higher than that of the grid circuit, a signal output circuit coupled with the anode circuit, a tuned feed-back control circuit having an inductive winding providing feed-back coupling between the anode circuit and the grid circuit, means for conveying feed-back current from the anode circuit through said winding differentially to provide differential in-phase and counter-phase inductive feed-back of energy to said grid circuit to vary the amplitude of oscillations therein, said last named means comprising a variable impedance element connected with one terminal of said winding, a second variable impedance element connected with the other terminal of said winding, and means for varying at least one of said impedance elements with respect to the other, thereby to provide a differential flow of feed-back energy through said winding and a corresponding variation in amplitude of grid circuit oscillations.

6. In an electronic tube oscillator system adapted to generate self-oscillations by feed-back, the combination of anode and grid circuits coupled to provide said oscillations in operation, additional means for feeding back energy from the anode circuit to the grid circuit comprising an inductance winding coupled to said grid circuit inductively, said winding having two inductive-

ly opposed portions, means for tuning said portions in series aiding inductive relation to the frequency of the anode circuit, circuit means connected with the anode circuit for conducting feed-back current through said winding portions in opposition to provide simultaneous positive and negative feed-back action differentially in said winding, means for controlling the flow of feed-back current through each of said winding portions to vary the differential feed-back effect and the strength of oscillations in the grid circuit, and means for deriving an electrical output effect from the anode circuit as a result of said variation.

7. In an electronic tube oscillator system, means providing a tuned anode circuit responsive to a predetermined frequency, means providing a tuned grid circuit responsive to a frequency of the order of and slightly lower than the first named frequency and having as a tuning element the reflected grid-to-anode capacity to said tube, a third tuned circuit responsive to the frequency of the anode circuit having an inductance element coupled with the anode circuit at substantially the inductive center of said element and providing loose inductive coupling with the grid circuit, means including said inductance element providing substantially balanced opposing feed-back paths from said anode circuit to ground of said system, means for inversely varying the impedance of said paths to vary the feed-back effect on the grid circuit in amplitude and phase thereby to modulate said oscillator system, and means providing a modulation signal output circuit connected with said anode circuit.

8. The combination with an electronic tube oscillator system having a tunable anode circuit and a tunable grid circuit for generating self-oscillations, of a feed-back winding coupled to said grid circuit and having a coupling connection from an intermediate point thereon to one side of the anode circuit, means for tuning said feed-back winding whereby the anode circuit may be resonated therewith, and a control circuit for said winding including a variable impedance element connected with each of the terminal ends of said winding and the other side of said anode circuit, thereby to provide controlled flow of feed-back current through said winding in opposite directions from said intermediate point and differentially positive and negative feed-back on said grid circuit in response to variation of said impedance elements.

9. The combination with a self-excited electronic tube oscillator system having a grid circuit and an anode circuit, of means for differentially applying feed-back from the anode circuit to the grid circuit comprising a feed-back inductance inductively coupled to the grid circuit and coupled to the anode circuit through a tap connection substantially at its inductive center, a control circuit comprising a pair of leads connected with the terminals of said inductance and extending therefrom in closely associated relation to each other, a variable impedance element connected between each of said leads and ground for said oscillator system, means for varying at least one of said impedance elements with respect to the other to vary the flow of feed-back energy through said inductance differentially thereby to vary the strength of oscillations in the grid circuit, whereby the anode current is correspondingly and proportionately varied, and means connected with the anode circuit for deriving output

signal variations in response to variations in anode current.

10. The combination with an electronic tube oscillator system having a tunable anode circuit and a tunable grid circuit for generating self-oscillations, of a feed-back winding coupled to said grid circuit and having a coupling connection from an intermediate point thereon to one side of the anode circuit, means for tuning said feed-back winding whereby the anode circuit may be resonated therewith, a control circuit for said winding, a fixed capacity electrode connected with each of the terminal ends of said winding through said control circuit, said electrodes being spaced, a movable capacity electrode located between said fixed electrodes and providing inversely variable capacity means therewith for controlling the flow of feed-back current through said winding in opposite directions from said intermediate point and differentially positive and negative feed-back on said grid circuit in response to variation of said impedance elements.

11. In an electronic tube oscillator system adapted to generate self-oscillations by feed-back, the combination with anode and grid circuits wherein said oscillations are established in operation, of additional means for feeding back energy from the anode circuit to the grid circuit comprising an inductance winding having two inductively opposed portions substantially equally coupled inductively with said grid circuit, means for tuning said inductance winding to the frequency of the anode circuit, circuit means connected with the anode circuit for conducting feed-back current through said winding portions in opposition to provide simultaneous positive and negative feed-back action differentially in said winding, means for variably controlling the flow of feed-back current through each of said winding portions to vary the differential feed-back effect and the strength of oscillations in the grid circuit, and means for deriving an electrical output effect from the anode circuit as a result of said variation.

12. The combination with an electronic tube oscillator system having a tunable anode circuit and a tunable grid circuit for generating self-oscillations, of a feed-back winding coupled to said grid circuit and having a coupling connection from an intermediate point thereon to one side of the anode circuit, means for tuning said feed-back winding whereby the anode circuit may be resonated therewith, a control circuit for said winding including a variable impedance element connected with each of the terminal ends of said winding and the other side of said anode circuit, thereby to provide controlled flow of feed-back current through said winding in opposite directions from said intermediate point, means for varying at least one of said impedance elements to provide differentially positive and negative feed-back on said grid circuit in response thereto, and means providing a modulation signal output circuit for said system.

13. An oscillator system comprising in combination, an electronic tube having an anode, a cathode and a control grid, a tuned anode circuit for said tube, a tuned grid circuit for said tube responsive to a frequency of the order of and slightly lower than the resonance frequency of the anode circuit and having as a tuning element thereof the reflected grid-to-anode capacity of said tube, a third tuned circuit responsive to the resonance frequency of the anode circuit, an inductance element in said last named circuit pro-

viding substantially loose inductive coupling with the grid circuit, means providing a coupling connection with the anode circuit at an intermediate point on said inductance element, means providing substantially balanced opposing feed-back paths through said inductance element from said intermediate point to the ground of said system, means for variably unbalancing the impedance of said paths to modulate said oscillator, and means providing a modulation signal output circuit for said system.

14. An oscillator system comprising in combination, an electronic tube having an anode, a cathode and a control grid, a tuned anode circuit for said tube, a tuned grid circuit for said tube responsive to a frequency of the order of and slightly lower than the resonance frequency of the anode circuit and having as a tuning element thereof the reflected grid-to-anode capacity of said tube, a third tuned circuit responsive to the resonance frequency of the anode circuit, an inductance element in said last named circuit coupled with the anode circuit at substantially the electrical center thereof and providing loose inductive coupling with the grid circuit, means including said inductance element providing substantially balanced opposing feed-back paths from said anode circuit to ground of said system, means for variably unbalancing the impedance of said paths to modulate said oscillator tube, and means providing a modulation signal output circuit for said system.

15. A self-excited electronic-tube oscillator system having a tuned grid circuit, an anode circuit and means to provide feed-back from the anode to the grid circuit, comprising a feed-back in-

ductance coupled to both the grid circuit and to the anode circuit, and having a coupling connection from an intermediate point thereon, by means of which connection coupling to one of said circuits is effected, and means for conveying feed-back current from the anode circuit through said inductance differentially to provide differential in-phase and counter-phase inductive feed-back of energy to said grid circuit to vary the amplitude of oscillations therein, as well as controlling the relative resonant frequencies of the circuits by reflected reactance.

16. An oscillator system according to 15, wherein the feed-back conveying means comprise a control circuit including at least one variable impedance having terminals respectively connected with each of the terminal ends of the inductance and with the other side of the circuit connected to the intermediate point of the inductance.

17. An oscillator system according to claim 15, including a pair of impedance elements and means for varying at least one of the impedance elements with respect to the other to provide inverse impedance variation thereof and modulation of the system.

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