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D. H. SLOAN
FEED-BACK SYSTEM FOR ELECTRONIC TUBES
COMPRISING HOLLOW BODY RESONATORS
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Fig. 1.

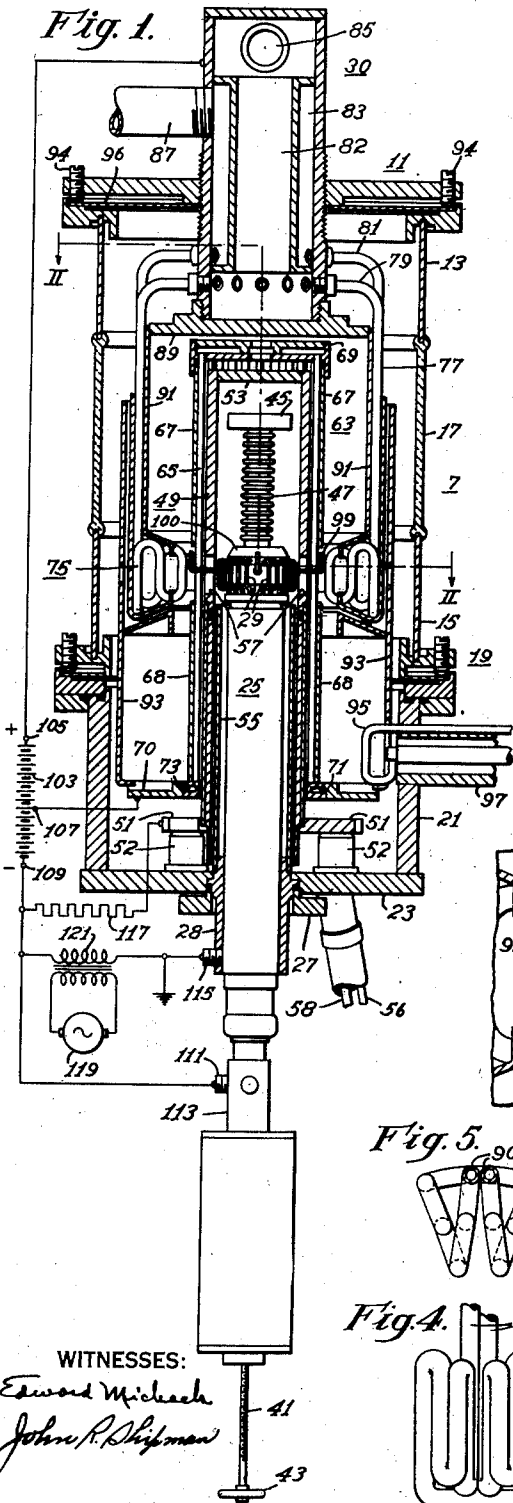


Fig. 2.

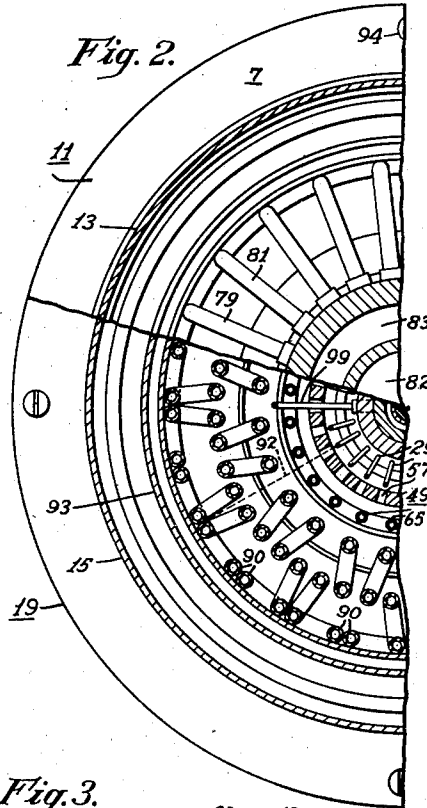


Fig. 3.

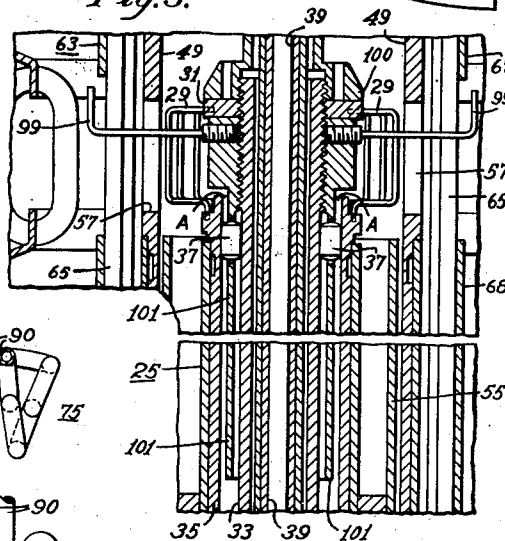


Fig. 5.

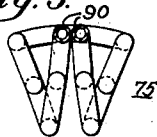
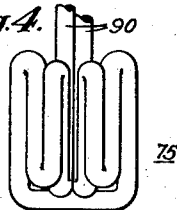


Fig. 4.



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2,459,593

FEED-BACK SYSTEM FOR ELECTRONIC
TUBES COMPRISING HOLLOW BODY
RESONATORS

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Application March 17, 1944, Serial No. 526,882

2 Claims. (Cl. 315—6)

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This invention relates to a feed-back system for electronic tubes and has particular relation to a feed-back system for use with a tube of the resnatron type for generating ultra high frequency power.

A tube of the resnatron type generally comprises a pair of resonators adapted to have electromagnetic oscillations of substantially the same frequency established therein. A cathode is mounted within the first resonator and an anode is mounted within the second resonator. The two resonators are positioned adjacent each other and have openings in the adjacent walls thereof to permit a flow of electrons from the cathode to the anode. One or more grids are located between the cathode and anode and preferably include a control grid formed by the wall of the first resonator about the openings therein and an accelerating grid formed by the wall of the second resonator about the openings therein. Means are then provided to supply current through the cathode to heat it and to impress a direct-current potential difference between the anode and cathode, the accelerating grid and cathode, and the control grid and cathode.

The resnatron tube operates as a tuned-plate, tuned-grid, class C oscillator with the first resonator in the control grid-cathode circuit and the second resonator in the anode or plate circuit. Each of the two resonators is designed to have a principal mode of oscillation in which the vector of the electric field is substantially parallel to the electron path between the cathode and anode and the fields within the resonators have a definite phase relationship. During operation the anode and accelerating grid have a relatively high, positive direct current voltage thereon relative to the cathode tending to liberate electrons from the cathode but the control grid has a negative voltage such that a group of electrons are liberated from the cathode only during the peak portion of each half cycle of the field in the first resonator in which that field tends to aid in effecting liberation of electrons and movement thereof toward the anode. Thus sharp pulses of electrons are liberated at regular intervals from the cathode.

After liberation, the electrons are accelerated in their movement toward the anode by the high voltage on the accelerating grid. The spacing between the cathode and anode with respect to the speed of the electrons provides an electron transit time of one-half cycle. Thus, the liberated electrons first receive energy from the oscillating field of the first resonator as well as from

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the direct current voltage fields but they enter the field of the second resonator while it opposes their motion and the electrons consequently give up energy to the field of the second resonator to produce the desired oscillations therein.

A portion of the power thus generated in the second resonator is fed back to the first resonator to maintain the desired oscillations therein. This feedback is accomplished through a concentric transmission line having one end coupled to the second resonator by a coupling loop of the usual construction and the other end coupled into the first resonator by another similar coupling loop. The coupling produces oscillations in the first resonator in which the control grid to cathode high frequency voltage is in phase with the anode to accelerating grid high frequency voltage. The remaining power is extracted from the second resonator by still another coupling loop connected to an output transmission line.

The resnatron tube, when properly constructed, operates as described. However, it has been found desirable to improve the feed-back coupling system and to increase the power output available from a tube of this type. The energy delivered by the electrons to the field of the second resonator may be increased by increasing the voltages impressed on the various elements which increases in turn the speed of the electrons entering the second resonator. With the increased speed, however, the transit time of the electrons is reduced. When the transit time of the electrons is reduced, an increase in the spacings between the elements along the electron path is required which in turn requires a higher voltage to maintain the electron speed so that a satisfactory power increase by this means is impractical.

The feed-back coupling system as used in prior tubes is a source of power loss as well as a source of considerable manufacturing difficulty. It is extremely difficult and almost impossible from a practical standpoint to avoid standing waves in the feed-back line. These standing waves cause appreciable power losses and introduce high voltage problems. In addition, glass seals are usually employed in the feed-back line to permit the maintenance of the necessary high vacuum within the tube. However, the high voltages, resulting from the standing waves in the feed-back line, are very destructive of the glass and, with gas in the form of air in the line, the seals are often broken during operation of the tube.

To avoid the troubles encountered with the glass seals, a vacuum-tight feed-back line has

been tried. However, such an arrangement introduces numerous other difficulties in sealing the entire line, especially since the line requires some kind of tuning arrangement, such as the familiar stud slider.

It is accordingly an object of my invention to provide a new and improved tube of the resnatron type.

Another object of my invention is to provide a new and improved resnatron tube having an increased power output.

A further object of my invention is to provide a novel resnatron tube having a new and improved feed-back system.

Still another object of my invention is to provide a novel resnatron tube having a highly efficient feed-back system which avoids the introduction of problems associated with maintaining a vacuum.

More specifically, it is an object of my invention to provide a new and improved resnatron tube having a novel feed-back system and an increased power output.

My invention arises from the realization that the direct-current voltages employed with the resnatron tube can be increased to increase the electron voltage, and, therefore, the power output, with the same spacings between cathode, grids and anode if the phase of the voltage component of the field within the first resonator between the control grid and cathode is shifted to lag by an amount of the order of 90 degrees behind the voltage component of the field of the second resonator between the anode and accelerating grid. If the voltage within the first resonator lags 90 degrees behind that in the second resonator instead of being in phase, the electron voltage may be increased by four times with the transit time of the electrons reduced to one-quarter cycle.

In accordance with my invention, a 90° phase shift of the field voltage of the first resonator relative to the second can be obtained by connecting a small capacity between the anode and cathode and tuning the first resonator, within which the cathode is mounted, to substantially the same frequency as the second resonator so that the cathode to control grid impedance is neither inductive nor capacitive. This capacity may be conveniently obtained by positioning a conductive member adjacent to, but spaced from, the anode, and conductively connecting the member to the cathode. Preferably, this arrangement comprises a molybdenum or tungsten wire attached to the cathode and extending through the grids into the anode region with the end portion of the wire bent at right angles to form a conductive member adjacent to, but spaced from, the anode. In some cases, where not as much capacity is required, the wire need not be bent at the end next the anode but instead may merely extend toward the anode with the end of the wire spaced therefrom.

The coupling wire may be attached to any part of the cathode other than a point of zero voltage with respect to the control grid, but is preferably connected at a region of maximum voltage. At this region on the cathode, the anti-resonant impedance of the cathode-grid circuit is at its largest value, with the grid-cathode voltage at a maximum and the current at a minimum. Such an anti-resonant impedance acts as a resistance connected in series with the capacitance existing between the wire and the anode. When the field in the second resonator is in a direction that the

anode is positive, current flows from the anode through the capacitance, wire and resistance. The voltage established across the resistance by the current leads the high frequency anode-accelerating grid voltage by about 90 degrees with the cathode positive relative to the control grid. Consequently, the field in the first resonator reaches a maximum in a direction aiding movement of electrons from the cathode to the anode 90 degrees behind the field of the second resonator and the field of the second resonator reaches a maximum in a direction opposing the motion of the electrons 90 degrees later. As a result, electrons leaving the cathode during the peak portion of a half-cycle of the first resonator field in which that field is in a direction aiding movement of the electrons, enter the second resonator when the field thereof is in a direction opposing the electron motion and the electrons give up energy to the field of the second resonator.

If the first resonator is tuned to a slightly different resonant frequency, the amount of phase shift is changed as may be necessary or desirable with different spacings and different direct-current voltages.

The novel features which I consider characteristic of my invention are set forth with more particularity in the accompanying claims. The invention itself, however, with respect to the construction and operation of an embodiment thereof, as well as further objects and advantages of the invention, may be best understood from the following description of a specific embodiment with reference to the drawing, in which:

Figure 1 is a cross-sectional view of a resnatron tube embodying my invention;

Fig. 2 is an enlarged, partial view of a cross-section of the tube shown in Fig. 1, as taken along line II—II;

Fig. 3 is an enlarged, partial view of a cross-section of the tube of Fig. 1 as taken along the axis;

Fig. 4 is an elevational view of one of the anode units; and

Fig. 5 is a top view of the anode unit shown in Fig. 4.

As shown in Fig. 1, the main portion of the resnatron tube is enclosed within a generally cylindrical chamber 7 comprising an upper, circular plate unit 11, two coaxial, cylindrical, metallic members 13 and 15 of the same diameter spaced apart by a coaxial, glass cylinder 17 of the same diameter sealed therebetween, with the upper cylindrical member 13 secured to the upper plate unit 11 and the lower cylindrical member 15 secured to an intermediate plate unit 19. Another cylindrical member 21 is secured to the bottom of the intermediate plate unit 19 and the lower end of member 21 is secured to a bottom plate 23. A cathode unit 25 extends through a central opening in the bottom plate 23, being secured therein by a cap member 27 and support 28. A cooling fluid, supply chamber body 30 is threadedly mounted in a central opening in the upper plate unit 11. The entire chamber 7 is sealed and a vacuum is created and maintained therein by a vacuum pump connected to the interior of the chamber by a passage which does not appear in Fig. 1.

The cathode unit 25 includes a plurality of cathode filament wires 29 spaced from each other but arranged to form a generally cylindrical cage-like structure in the center and about the axis of the chamber 7, and a plurality of concentric

tubular members as shown in Fig. 3. Complete details of the cathode unit 25 are disclosed in my copending application, Serial No. 526,883, filed March 17, 1944 and now U. S. Patent No. 2,451,987, granted October 19, 1948.

The upper ends of the filament wires 29 are soldered about the circumference of a threaded nut 31 which is mounted on the upper end of one of the tubular members 33 of the cathode unit 25. From the nut 31, each filament wire 29 extends radially outward a short distance and then downwardly, parallel to the axis, with the lower end of the filament wire extending radially inward toward the axis and secured to another tubular member 35 within the cathode unit. The two tubular members 33 and 35 to which the filament wires 29 are attached are spaced from each other by insulating pellets 37. The central tubular member 39 of the cathode unit 25 extends upwardly beyond the filament wires 29 to a tuning plate 45. The tubular member 39 is movable vertically to move the tuning plate 45, by rotation of the hand wheel 43 at the bottom of the resonator tube. The tuning plate 45 is connected to the tubular member 33 through a flexible bellows 47.

A cylindrical member 49 of conductive material is also positioned coaxially within the chamber 7 and surrounds the cathode unit 25. This member 49, hereinafter called the control grid member, is mounted on another horizontal plate 51 supported from bottom plate 23 by a plurality of insulators 52. An end plate 53, spaced from the tuning plate 45, extends across the upper end of the control grid member. The lower end of the control grid member 49 is spaced from the cathode unit 25 but is associated with still another tubular member 55, mounted on the support 28 for the cathode unit 25, to form a choke for high-frequency oscillations. With this structure, a first resonator is formed by the plate 53, the control grid member 49, member 55, and the cathode unit 25, the cathode filament wires 29 being positioned within this first resonator. A cooling fluid, such as water, is supplied through an inlet pipe 56 and plate 51 to cool the control grid member 49, in a manner fully disclosed in my aforesaid copending application, and passes out outlet pipe 58.

Openings 57 are provided in the wall of the control grid member 49 opposite each of the filament wires 29, as illustrated in Fig. 2 to provide a grid. Means are also provided to cool the control grid member 49 but they are not visible in the cross-section of Fig. 1 but are illustrated in my aforesaid copending application.

A cylindrical unit 63, designated the accelerating grid unit, comprises a plurality of vertical pipes 65 of conductive material arranged to outline a cylinder concentric with, and surrounding, the control grid member 49. The pipes 65 are spaced from each other, as shown in Fig. 2, so that in the region of the filament wires 29, the spaces between adjacent pipes are radially opposite corresponding filament wires 29 and openings 57 in the control grid member, whereby the pipes 65 form a grid. Secured to and surrounding the pipes 65 above the region of the filament wires is a conductive metal cylinder 67. A similar cylinder 68 surrounds the pipes 65 below the region of the filament wires. A cap 69 is secured across the top of the cylinder 67 and has openings in the bottom thereof into which the pipes 65 extend, the cap having an internal passage in

communication with the open ends of all of pipes 65.

The entire accelerating grid unit 63 is mounted on a horizontal plate 70 which is supported from the bottom plate 23 by a plurality of insulators (not shown). A cooling fluid, such as water, is supplied through an inlet pipe (not shown) and an internal passage 71 in plate 70 to one-half of pipes 65. The fluid flows up these pipes to cap 69 and returns through the other half of the pipes to another internal passage 73 in plate 70 connected to an outlet pipe (not shown).

The bottom of the cooling fluid chamber body 30 within the chamber 7 has a plate 89 secured thereon which is spaced from the cap 69 on the accelerating grid member 63. This plate 89 is circular and supports a cylindrical member 91 which in turn supports the anode structure. Another cylindrical member 93 of slightly larger diameter than the anode supporting member 91 is mounted on the lower plate 70 and extends upward with its upper end surrounding the anode supporting member and cooperating therewith to form a quarter wave length, high frequency choke. These two members 91 and 93 with the plate 89, lower plate 70 and the accelerating grid member 63 with its cap 69 form a second resonator.

The anode of the resonator tube comprises a plurality of anode units 75, as shown in Figs. 1, 4 and 5, arranged within the second resonator in a circle around the accelerating grid. Each of the anode units 75 comprises a convoluted section of a hollow pipe 77 of highly conductive material, such as copper, through which a cooling fluid, such as water, is to be passed. The two ends 79 and 81 of the hollow pipe extend upwardly from the convolutions with one end 79 connected to a cooling fluid chamber 32 in body 30 supplied with cooling fluid from an inlet pipe line 85 and with the other end 81 connected to another chamber 33 in body 30 from which fluid is removed through an outlet line 87.

The convolutions of each anode unit includes a plurality of substantially parallel and coextensive, vertical, pipe portions which are slightly longer than the slots in the accelerating and control grids and, of course, are parallel to the vertical filament wires 29. When all of the plurality of anode units are arranged adjacent each other in a circle about the accelerating grid as shown in Fig. 2, that part of the complete anode having the largest diameter is made up of pairs of adjacent, vertical pipe portions 90 in engagement with each other with each pair positioned radially opposite a filament wire 29 so that the center line of the electron path from a filament wire may be represented by dotted line 92. The other convolutions cooperate with each pair 90 to outline a groove radially opposite each filament wire into which the corresponding electron path projects. Further details of the anode structure and the objects and advantages thereof are disclosed in my copending application, Serial No. 526,883, filed March 17, 1944.

A plurality of feed-back coupling wires 99 are attached at one end to the cathode unit 25 in the first resonator and extend radially through the grids 59 and 61 into the second resonator. Preferably, four of these coupling wires are employed, the number, of course, depending upon the amount of feed-back power required to operate the first resonator. As shown in Figs. 2 and 3, each of the coupling wires 99 is secured to the end of a tubular member 101 threadedly engaged

with the tubular member 33 supporting the upper end of the filament wires 29 and extends radially through a set of openings in the grids for which the filament wire is omitted. The outer end portion of each coupling wire is bent at right angles to form a conducting member adjacent and parallel to, but spaced from, the anode. Thus the coupling wire 99, in effect, provides a capacitance connected between the anode and cathode.

As previously mentioned, the end portion of the coupling wire need not be bent in some cases. It is also to be noted that the omission of a filament wire for each coupling wire may be avoided by connecting the coupling wire to the base 100 of bellows 47 and extending it radially above the filament wires through slightly enlarged openings in the grids.

The two resonators are designed so that their electric field vectors are along radial lines. Consequently, alternate points of minimum and maximum voltage appear along the length of the cathode unit 25. The coupling wires 99 may be connected to the cathode unit at any point other than a zero voltage point. However, it is preferable to connect the coupling wires at a point of maximum voltage with respect to the control grid. This is the point of minimum current and the anti-resonant impedance of the cathode-grid circuit with the first resonator tuned to the same resonant frequency as the second resonator acts as a resistance connected in series with the capacitance existing between the coupling wire and the anode. The voltage drop across the resistance is then shifted on the order of 90 degrees in phase relative to the high frequency voltage between the anode and accelerating grid. As previously explained, the voltage drop across the resistance is effective to maintain the oscillations in the cathode resonator with the field of the first resonator rising to a maximum in the direction aiding movement of the electrons 90 degrees behind the field in the second resonator. If the coupling wires are connected at some point other than that of maximum voltage, the impedance of the cathode-grid circuit is smaller and a greater capacity would be required to feed back the same power. Tuning of the first resonator to another frequency changes the effect of the impedance and produces a different phase shift. It is to be noted that the second resonator may also be tuned by raising or lowering plate 89 by screws 94 which may be used to bend the diaphragm 96.

The cathode unit 25 also includes another concentric tubular member 101 positioned between the members 33 and 35. The tubular member 101 is connected at its upper end to the member 33 but is spaced from the tubular member 35 and extends downwardly for a distance equal to the one-quarter wave length. Thus a low impedance is established between member 35 supporting the lower ends of the filament wires 29 and the member 33, supporting the upper ends of the filament wires and the coupling wires, at the point A. This, in effect, provides a short circuit for high-frequency currents in the filament and coupling wires and prevents the escape of high-frequency power through the filament supply circuit which is connected to tubular members 33 and 35.

Direct-current voltages are impressed on the anode, cathode and grids of the resonatron tube as shown schematically in Fig. 1. A source of direct-current potential, such as a battery 103, has its positive terminal 105 connected to the body 30 and, therefore, to the anode. An intermediate tap 107 on the battery 103 is connected to the

plate 70 supporting the accelerating grid member 63 and the negative terminal 109 is connected through a threaded plug 111 in housing 113 to the tubular member 33 which is connected to the upper ends of the filament wires. The tubular member 35 supporting the lower ends of the filament wires is grounded through the threaded plug 115 in the support 28. Filament current is supplied from a source 119 through a transformer 121 connected to plugs 111 and 115. The control grid member 49 is connected through the plate 51 which supports it and a resistor 117 to the negative terminal 109 of the battery 103. Typical direct current voltages which have been used in operating a resonatron tube constructed according to Fig. 1 with a 90 degree phase displacement in the fields, establish the anode at 10,000 volts and the accelerating grid at 7,000 volts. The control grid is originally at zero voltage but when the oscillations are initiated, current flows from the control grid to the cathode and the resulting potential developed across the resistor 117 causes the control grid to build up to a voltage of approximately minus 1,000 volts. With other field displacements different voltages should be used.

In operating the resonatron tube, the two resonators are first tuned to substantially the same frequency by means of handwheel 43. The direct-current voltages are then applied to the elements in the tube and oscillations are initiated, building up gradually until the control grid reaches operating voltage. Then in a half-cycle when the field within the first resonator is in a direction to aid movement of the electrons, a group of electrons are liberated from the cathode during the peak portion only of the half-cycle and move toward the anode, picking up energy from the high-frequency field of the first resonator and the direct-current voltage fields between the anode and cathode and the accelerating grid and cathode. The accelerating grid, being at a comparatively high positive potential, supplies considerable energy to the electrons and greatly increases their speed. With this greatly increased speed, the electrons enter the second resonator approximately one-quarter of a cycle after leaving the cathode and with the phase displacement of the order of 90 degrees between the fields of the first and second resonators, the field of the second resonator is, at that time, in a direction opposing the motion of the electrons. Consequently, the electrons give up energy to the field of the second resonator producing the oscillations therein. Sufficient power is fed back from the second resonator to the first resonator through the coupling wires 99 to maintain the oscillations in the first resonator and the greater remaining power in the second resonator is extracted by a coupling loop 95 and fed to an output line 97.

It is to be noted that the feed-back coupling wire provides an efficient feed-back system requiring but a very low current with low losses and avoids any vacuum problems. In addition, the coupling wire provides a suitable phase-shifting circuit to displace the phase of the field of the first resonator with respect to the field of the second resonator and thus enables higher direct-current voltages to be employed resulting in a greater output power from the tube.

Although I have shown and described a specific embodiment of my invention, I am aware that other suitable modifications may be made. I, therefore, do not intend to limit my invention to the specific embodiment disclosed.

I claim as my invention:

1. An electronic tube apparatus comprising a pair of hollow body resonators adapted to have electromagnetic field oscillations established therein, an anode mounted within one of said resonators, a cathode mounted within the other of said resonators, said pair of resonators being adjacent each other with openings therein between said anode and cathode permitting a flow of electrons from said cathode to said anode, a control grid between said cathode and anode, circuit means connected to said anode and cathode for establishing a direct current potential field therebetween tending to liberate electrons from said cathode and move them toward the anode, additional circuit means connected to said grid and cathode for establishing a direct current potential field permitting electrons to be liberated from the cathode during the peak portion only of a half-cycle of the field within said other resonator in which it is of a polarity to add energy to the electrons, the strengths of said fields moving said liberated electrons toward said anode with a speed causing them to pass through said one resonator to said anode while the field therein opposes their motion and absorbs energy therefrom, and a feed-back coupling between said resonators for supplying energy from said one resonator to said other resonator to maintain the field therein at substantially the same frequency but displaced in phase relative to the field of the second resonator, said coupling comprising a conductor connected at one end to said cathode and extending into said one resonator with the other end thereof adjacent to, but spaced from, said anode to form a capacity connected between said anode and cathode, and tuning means connected to one of said resonators for adjusting the resonant frequency thereof whereby the amount of said phase displacement may be adjusted.

2. An electronic tube apparatus comprising a pair of hollow body resonators adapted to have electro-magnetic field oscillations established therein, an anode mounted within one of said resonators, a cathode mounted within the other of said resonators, said pair of resonators being adjacent each other with openings therein be-

tween said anode and cathode permitting a flow of electrons from said cathode to said anode, a control grid between said cathode and anode, circuit means connected to said anode and cathode for establishing a direct current potential field therebetween tending to liberate electrons from said cathode and move them toward the anode, additional circuit means connected to said grid and cathode for establishing a direct current potential field permitting electrons to be liberated from the cathode during the peak portion only of a half-cycle of the field within said other resonator in which it is of a polarity to add energy to the electrons, the strengths of said fields moving said liberated electrons toward said anode with a speed causing them to pass through said one resonator to said anode while the field therein opposes their motion and absorbs energy therefrom, and a feed-back coupling between said resonators for supplying energy from said one resonator to said other resonator to maintain the field therein at substantially the same frequency but displaced in phase relative to the field of the second resonator, said coupling comprising a conductor connected at one end to said cathode at a point of substantially maximum high frequency field voltage and extending into said one resonator with the other end thereof adjacent to, but spaced from, said anode to form a capacity connected between said anode and cathode, and tuning means connected to one of said resonators for adjusting the resonant frequency thereof whereby the amount of said phase displacement may be adjusted.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,088,722	Potter	Aug. 3, 1937
2,157,952	Dallenbach	May 9, 1939
2,287,845	Varian et al.	June 30, 1942
2,389,271	Mouromtseff et al.	Nov. 20, 1945