May 16, 1950 A. V. HAEFF 2,507,972

ELECTRON DISCHARGE DEVICE AND ASSOCIATED CIRCUITS

Original Filed July 25, 1942 3 Sheets-Sheet 1

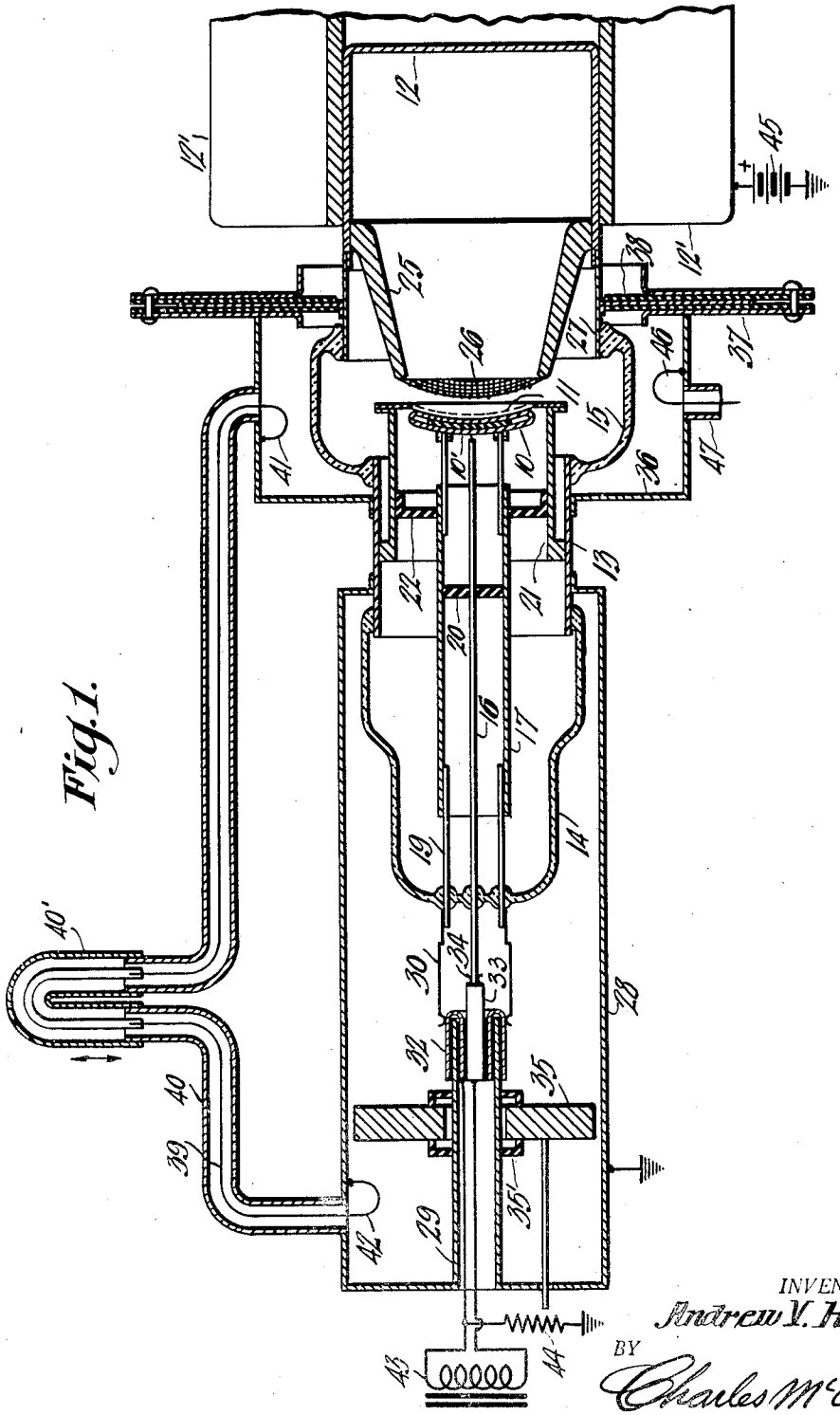


Fig. 1.

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Original Filed July 25, 1942 3 Sheets-Sheet 2

Fig. 2.

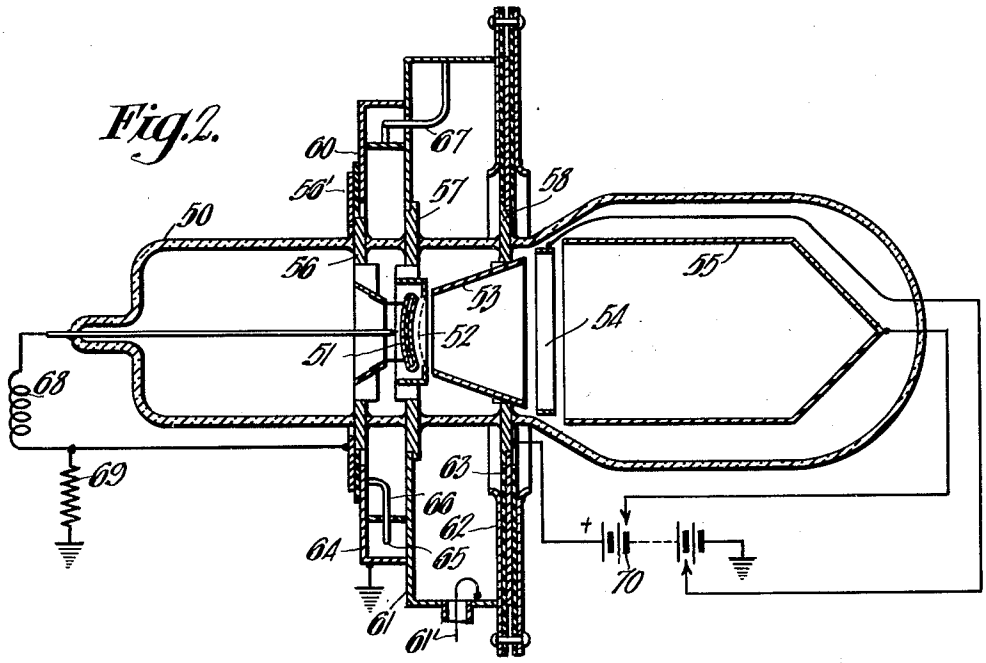
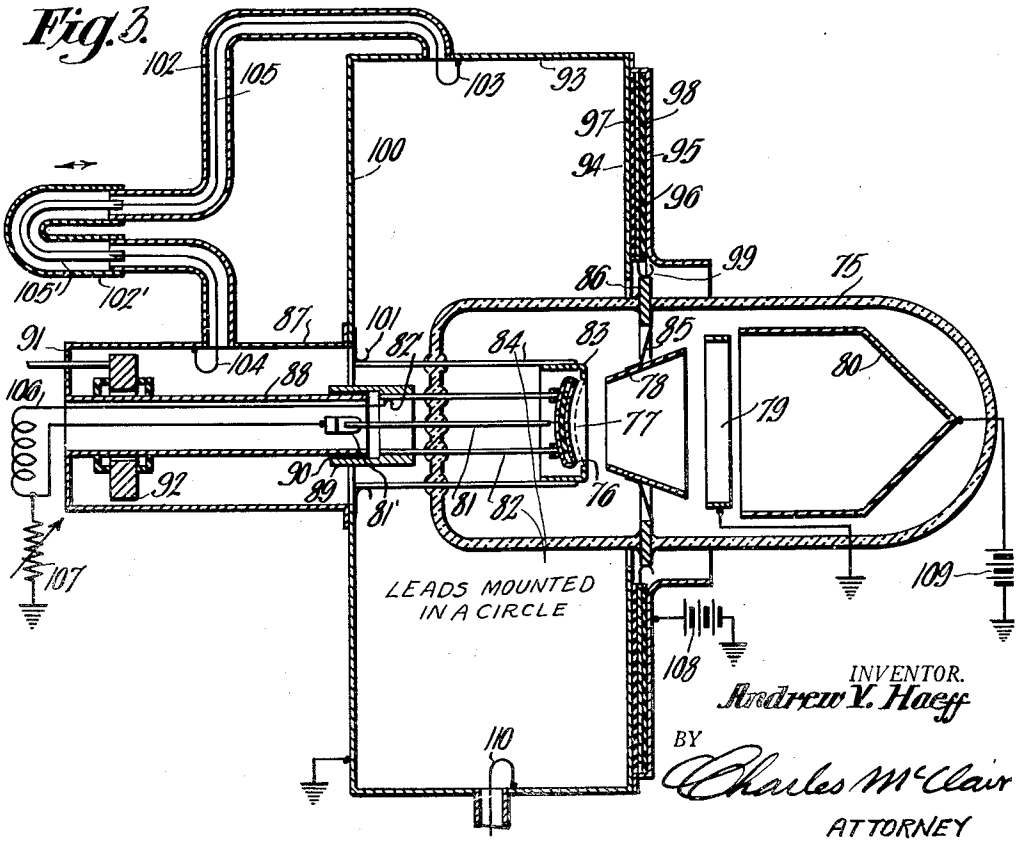


Fig. 3.



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Original Filed July 25, 1942 3 Sheets-Sheet 3

Fig. 4.

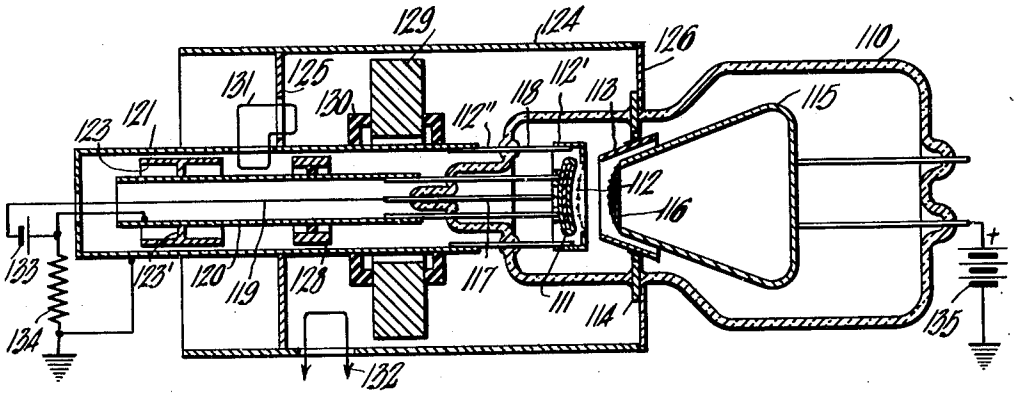
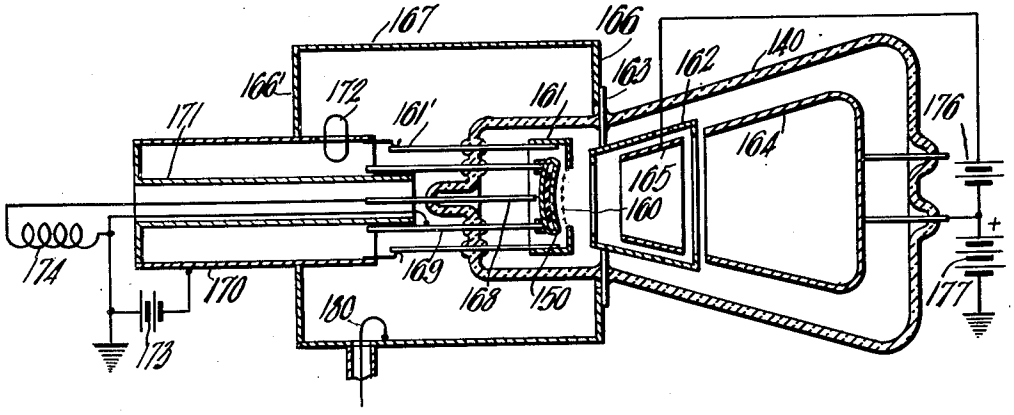


Fig. 5.



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UNITED STATES PATENT OFFICE

2,507,972

ELECTRON DISCHARGE DEVICE AND ASSOCIATED CIRCUITS

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Original application July 25, 1942, Serial No. 452,302. Divided and this application December 8, 1944, Serial No. 567,226

4 Claims. (Cl. 315—39)

1

My invention relates to electron discharge devices and associated circuits particularly suitable for ultra high frequencies as high power output tubes which are useful as amplifiers or oscillators.

This application is a division of my copending application, Serial No. 452,302, filed July 25, 1942, now Patent 2,400,753, and assigned to the same assignee as the present application.

In electron discharge devices intended for high power output and particularly for use at ultra high frequencies, close spacing of the electrodes and high operating voltages are requisites. Optimum operating conditions for maximum output require a maximum instant grid voltage and a minimum instant plate voltage when the peak plate current flows. However, for the usual electron discharge device undesired grid emission due to electron bombardment from the cathode and heating of the grid by radiated heat from the electron collecting surface of the anode or collector may result. Grid and plate circuit loading, burning out of the grid and increased heating at the anode, which represents wasted energy and hence a lowering of the efficiency of the electron discharge device, may occur under these conditions.

In the case of oscillators either self-biasing resistors may be used or fixed bias may be used to obtain the proper biasing voltage on the grid. Where a self-biasing resistor is used between grid and cathode, when the grid is positive, electrons strike the grid and cause secondary emission, which results in current flowing in the grid circuit. This results in a higher positive bias being placed on the grid, thus further increasing the positive grid potential and the velocity of the electrons bombarding the grid. This building up of the positive bias on the grid may cause the grid to burn out.

In the case of a fixed bias, while the bias itself does not increase, nevertheless when the grid is at positive peak and the plate voltage is at a minimum positive voltage, electrons striking the grid cause it to heat up, thus causing emission from the grid. Electrons emitted from the grid during the next half cycle, when the grid is negative and the anode positive, cause the electrons from the grid to be accelerated toward the anode with maximum velocity. These high velocity electrons strike the anode with considerable force and dissipate their energy in heat. Thus, energy is wasted and does not go into the output as useful energy. This grid

2

emission current, of course, also loads down the plate circuit, another undesirable factor.

In order to minimize grid emission, lower peak grid voltages are required, which as pointed out above means higher plate voltages with lower plate efficiency. It is desirable to have the electrons collected by the plate at a low velocity and to remove the electron receiving surface away from the grid to reduce heat absorbed by the grid. But with the usual three-electrode arrangement with the collector anode at a high positive voltage in order to draw the necessary plate current, this is not entirely feasible.

It is, therefore, an object of my invention to provide an electron discharge device having a high power output and which is suitable for use at ultra high frequencies as an amplifier or oscillator.

More specifically, it is another object of my invention to provide an electron discharge device in which grid emission is substantially reduced.

A still further object of my invention is to provide an electron discharge device in which the electrons may be collected at a low velocity to reduce the energy dissipated in heat.

These and other objects will appear hereinafter.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, but the invention itself will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 is a longitudinal section of an electron discharge device and associated circuit made according to my invention and Figures 2, 3, 4 and 5 show longitudinal sections of modifications of the electron discharge device shown in Figure 1.

In Figure 1 I provide an apparatus which can be used as a high power triode amplifier or as an oscillator. It includes an indirectly heated cathode 10 followed by a grid 11 and an anode or collector 12 having cooling fins 12'. The envelope is formed by means of the conducting collar member 13 closed at one end by the cup-shaped insulating member 14 and at its other end by the insulating collar member 15 and collector 12 provided with the collar member 27 sealed to the collar 15. The cathode heater 10' is provided with a lead 16 extending through the envelope. The cathode 10 is supported by means of the conductors and leads 18 arranged in a circle around conductor 16 and secured at one end to the elongated tubular member 17, the other end of the tubular member 17 being secured

to the leads 19 extending through the envelope. Members 17, 18 and 19 serve as the other lead for the cathode heater and as the cathode lead. Insulating disc 20 properly centers conductor 16 with respect to tubular member 17. The grid 11 is supported by means of conducting collar member 21 secured to the tubular conducting member 13 forming part of the tube envelope, the grid and cathode supports being separated by means of the insulating disc 22. The collector 12 is provided with the member 25 decreasing in diameter toward the grid to protect the seal and provide a proper field for the electrons. Across the opening is placed the wire mesh 26 for bringing about the proper field formation through which the electrons pass from the grid to the interior of the collector 12. This has the effect of minimizing effective transit time between grid and anode.

The input circuit connected between the grid and cathode comprises the elongated outer tubular member 28 electrically connected to the collar member 13 and an inner tubular member 29 capacity coupled at its inner end to the element 32 contacted by the spring-like elements 30 secured to the cathode leads. The member 32 electrically connected to the elements 30 provides one conductor through which the heating current flows to the cathode heater. The inner conductor 16 is engaged by means of a spring clip member 34 positioned on element 33 capacity coupled to element 32. This arrangement provides means through which the cathode direct current flows to the heater and at the same time provides a path for radio frequency currents. It will thus be observed that the grid 11, collar 21, collar 13, member 28, member 29, capacity coupling element 32, leads 30 and 19, tubular member 17 and leads 18 provide a coaxial line type resonator cavity circuit completely isolated from other circuits. It is tuned by means of the collar-like element 35 slidably supported on the inner tubular member 29 by means of the insulator support 35'.

The output circuit includes a drum-like member 36 of larger diameter than tubular member 28 electrically connected to collar 13 of the envelope and provide with a disc-like element 37 capacity coupled to the disc-like element 38 positioned transversely of the collar member 27 of the collector 12 and electrically connected thereto. The diameter of tubular member 28 is of the order of one half the diameter of member 36, as shown in Fig. 1. Energy from the output tank circuit is coupled back to the input circuit by means of the coaxial transmission line comprising inner conductor 39 and outer conductor 40. This line is made adjustable to insure proper phase relationship of the energy feedback with respect to the voltages in the input circuit, the inner conductor being provided with coupling loops 41 and 42. This adjustable transmission line is described in greater detail and claimed in my copending application Serial No. 455,175, filed August 18, 1942, now U. S. Patent 2,440,089, dated April 20, 1948 and assigned to the same assignee as the present application. These coupling loops could be made adjustable to control the amount of feedback. This arrangement permits both the input and output circuits to be adjusted independently of each other and for optimum operating conditions. The output is taken by means of loop 46 which feeds into the coaxial transmission line 47.

The transformer 43 supplies heating current for the cathode heater, and resistor 44 provides the biasing voltage between the grid and cathode. The anode or collector voltage is supplied by means of voltage source 45.

In operation an alternating high frequency voltage applied between the grid 11 and cathode 10 modulates the electron stream passing to the collector 12. The modulated electron stream in passing across the gap between the grid 11 and the surface of the mesh closure member 26 induces a voltage in the resonant cavity 36 coupled between the grid and the collector, thus energizing this resonant cavity circuit. Energy is then fed back by means of coupling loop 41, transmission line 39—40 and coupling loop 42 within the coaxial transmission line acting as the input resonant cavity circuit and comprising members 28 and 29. Tuning of the input circuit is accomplished by means of the tuning collar 35 which may be moved longitudinally of the input circuit.

Output may be taken from the resonator 36 by means of the coupling loop 46 and coaxial transmission line 47. In order to feed the energy from the output resonator to the input resonant cavity circuit in proper phase, the length of the transmission line 39—40 may be varied by varying the position of the movable U-shaped element 40' of this line to increase or decrease the length of the line.

In the apparatus shown in Figure 1, the input and output circuits are completely isolated from each other. Due to the fact that electrons are collected at a surface far removed from the grid 11, little radiated heat is absorbed by the grid. This eliminates much of the difficulty due to grid emission caused by absorption of heat due to the energy dissipated at the surface of the collector. The large collar-like support 21 for the grid acts as a means for conducting heat away from the grid rapidly to thus further maintain the grid at a low temperature. In effect close spacing of the electrodes is obtained by means of the structure shown without actually placing the collecting surface close to the grid, thus making the device suitable for use at ultra high frequencies where transit time between the electrodes becomes important. The capacity coupling between the output circuit and the anode or collector permits different voltages to be applied to the circuit and the collector and yet at the same time provides a resonant cavity type of circuit which is particularly suitable for use at ultra high frequencies. The apparatus shown in Figure 1 can be used either as an amplifier or oscillator by controlling the amount and phase of the energy fed into the input circuit.

In Figure 2 is shown a modification of the device shown in Figure 1 and employing ring type seals. The modification shown in this figure has an added advantage in that the collector may be maintained at a low voltage with respect to some other electrodes within the tube so that the electrons can be collected at a lower velocity than is possible in the apparatus shown in Figure 1, thus further increasing the efficiency of the tube.

The envelope 50 contains an indirectly heated cathode 51, grid 52, output and accelerator electrode 53, ring-like secondary electron suppressor 54 and cup-shaped collector 55. The cathode, grid and accelerator electrodes are supported by means of ring members 56, 57 and 58 sealed through the glass envelope. These ring members provide low loss, low inductance leads for the electrodes and merge into the circuits utilized with the device.

The input circuit comprises a flat drum-like

member 60 electrically connected to the ring 57 and capacitively coupled to the cathode ring 56 by means of the disc-like member 56' electrically connected to the cathode ring 56. The output resonant cavity comprises the drum-like member 61 having a wall 62 capacitively coupled to the flat disc-like element 63 electrically connected to the accelerator electrode ring 58. The two circuits are coupled by means of a transmission line formed by an annular-shaped member 64 surrounding the input circuit. Within member 64 is supported the inner conductor 65 having coupling loop 66 positioned within the input circuit and a coupling loop 67 positioned in the output circuit. This transmission line permits in effect a long line occupying a small space.

Cathode heating energy is supplied by means of the transformer 68 and the grid biasing voltage supplied by means of the dropping resistor 69. The collector electrode and suppressor electrode voltages are supplied by means of the voltage source 70, the suppressor being at the lower potential. The output is taken in the usual way by loop 61'.

With the arrangement shown the accelerator electrode 53 is maintained at a high potential sufficient to draw a large cathode current. Practically no current is drawn by the accelerator 53 so that little energy is dissipated in this electrode. Collector 55 which is outside the radio frequency circuit may be maintained at a lower potential than would be the case if it acted as an output electrode and hence electrons are collected at a lower velocity so that energy wasted as heat is reduced. The input and output circuits are completely isolated from each other and the amount of feedback can be controlled as well as its phase by means of the transmission line which can be made adjustable.

In the apparatus shown in Figure 2 an alternating high frequency voltage applied between cathode 51 and grid 52 modulates the electron stream from cathode 51 and which passes to the accelerator and output electrode 53 and is collected by collector 55, secondaries from 55 being suppressed by electrode 54. The modulated electron stream in passing across the gap between grid 52 and accelerator 53 induces a voltage across the gap, causing energization of the resonator 61. The accelerator 53 is capacitively coupled by means of the element 58 and wall 62 of resonator 61, the radio frequency field being confined within this resonator. The collector, therefore, is external to the radio frequency circuit. The input resonant cavity circuit comprises resonator 60 electrically connected to the grid 52 through collar 57 and capacitively coupled for radio frequency to the cathode by means of elements 56' and the radially directed ring-like conducting support 56 of the cathode 51. Energy is fed back into the input circuit by means of the transmission line comprising the loop 67, coil 65 within the annular box-shaped arrangement 64 and loop 66 within the input resonator. This causes the device to operate as an oscillator.

In Figure 3 is shown a further modification of the construction shown in Figure 2 and provided further with an adjustable transmission line for controlling the phase of feedback. In this modification the envelope 75 contains the indirectly heated cathode 76, grid 77, output and accelerator electrode 78, suppressor electrode 79 and collector 80, the cathode heater being supplied through the conductor 81 and conductors 82 mounted in a circle and surrounding the conductor 81 and serving as a support for the cathode. The grid is supported on collar 83, which in turn is supported on leads and support wires 84 mounted in a circle and surrounding conductors 82 and extending through the envelope of the tube. The accelerating electrode is supported by means of radially directed collar 85 connected to and supported by the radially directed ring-like conductor 86 extending through the envelope.

The input circuit comprises the elongated outer tubular member 87 electrically connected to the elongated inner tubular member 88 by means of the closure member 91. The inner tubular member 88 is capacitively coupled to the collar 89 secured to the outer ends of the leads and supports 82, the insulating collar 90 serving to separate members 88 and 89. The input circuit may be tuned by a member 92 slidable longitudinally of the input circuit.

The output tank circuit includes the resonant cavity structure comprising the member 93 and having one wall 94 provided with an outside annular member 95 in which the conducting disc 96 is supported by means of insulating discs 97 and 98. This disc is provided with spring contact engaging members 99 contacting member 86. This construction permits the envelope to be withdrawn from the output tank circuit and disengaged therefrom. Another wall 100 of the resonant cavity is supplied with spring contact members 101 engaging the conductors supporting the grid. The cathode heating circuit includes transformer 106 connected to leads 81 and 82 by spring contact members 81' and 82'. Voltage source 103 supplies accelerator electrode 78 maintained at a higher potential than the collector by means of voltage source 109. Thus, the envelope and its electrodes may be disengaged from the circuits by pulling the envelope to the right.

Energy may be returned to the input circuit to neutralize input losses or cause the tube to function as an oscillator by means of the transmission line having inner conductor 105 and outer conductor 102, one end being provided with coupling loop 103 and the other with coupling loop 104. Intermediate the concentric transmission line is a U-shaped adjustable portion comprising the conductors 105' and 102', which are telescopically engaged with the coaxial line. Thus, by varying the length of this line the phase relationship of the energy fed back from the output circuit to the input circuit can be controlled to insure the desired phase relationship. The output is taken by means of coupling loop 110. Otherwise the apparatus functions in a manner similar to that shown in Figure 2.

In Figures 4 and 5 are shown modifications of the constructions shown in Figure 3 in which the outside condenser coupling arrangement for the accelerator is avoided. In the arrangement shown in Figure 4 the envelope 110 encloses the cathode 111, control grid 112, accelerator and output electrode 113, and collector 115 having a mesh conductor 116 positioned across the opening for providing the proper field between the electrodes.

The cathode 111 is provided with an inner heater conductor 117 and outer conductors and leads 118 surrounding conductor 117, the input circuit being provided by means of the elongated tubular member 120 capacitively coupled to the elongated outer tubular member 121 by means of the collar 123 having a supporting disc 123' connected between it and the inner tubular member 120. Member 121 is connected to grid leads 112'' connected to collar 112' of grid 112.

The output electrode 113 is provided with a radially extending supporting and conducting member 114 electrically connected to the disc 126 closing one end of the tubular member 124 which is closed at the other end by means of the disc 125 to provide the output tank circuit of the resonator type connected between the grid and output electrode. The output circuit is energized in the usual way by inductive effect when the modulated stream of electrons passes across the gap between grid 112 and output electrode 113. Tuning of the input circuit is accomplished by means of the collar member 128 movable longitudinally of the input circuit, and the output circuit is tuned by means of the collar 120 supported on insulating elements 130 also slidable axially of the output circuit.

Coupling between the input and output circuits is provided by means of the coupling loop 131, the output being taken by means of output coupling loop 132. Cathode heating current is provided by voltage source 133 and proper bias on the grid by means of dropping resistor 134. The collector voltage is supplied by means of voltage source 135.

Thus the electrode 113, which is maintained at control grid potential serves to minimize capacitance between the control grid and collector. Large capacitance between the collector and electrode 113 serves to by-pass radio frequency currents. The electron collecting area of the collector is far removed from the control grid and cathode so that the grid may be run quite cool.

In Figure 5 is shown another arrangement in which the collector may be maintained at a lower positive potential than the output electrode or accelerator. A separate high positively biased electrode is used to get high peak currents. This electrode does not take current. The collector is outside of the radio frequency circuit and has a potential applied only sufficient to collect the electrons. Thus, there results a high efficiency apparatus of the kind shown in Figure 3, but without the need of an external capacity coupling arrangement.

In this arrangement the envelope 140 contains the cathode 150, and grid 160 supported on collar 161. The screening and shielding electrode 162 is supported by the radially extending support and lead arrangement 163 which extends through the wall of the envelope. The collector 164 is positioned to receive electrons from the cathode, the accelerator electrode 165 being positioned within the screen electrode 162.

The input circuit comprises the elongated outer tubular conductor 170 connected to the grid leads and supports 161' and the elongated inner tubular member 171 which is connected to the cathode leads and support 169. The output circuit comprises the resonant cavity circuit 167 having a wall 168 electrically connected to the radial leads 163 and another wall 166' electrically connected to the tubular member 170. The two circuits are coupled by means of the coupling loop 172. Cathode heating current is supplied by means of transformer 174 through lead 168 and leads 169 and grid bias voltage by means of voltage source 173. The accelerator and collector voltages are supplied by potential sources 176 and 177. The output is taken by coupling loop 130.

In the last arrangement described the collector is maintained at a lower potential than the accelerator.

High frequency apparatus made according to my invention eliminates or substantially reduces the difficulties due to grid emission. Efficiency is increased by providing means for collecting the electrons at low velocity. This is accomplished while at the same time providing high power outputs whether the apparatus is used as an amplifier or oscillator. My apparatus also provides a ready means for disconnecting the electrodes from the associated circuits, thus making available an electron discharge device and an associated circuit apparatus permitting ready replacement in case of damage to the tube or where replacement is desired for other reasons.

While I have indicated the preferred embodiments of my invention of which I am now aware and have also indicated only one specific application for which my invention may be employed, it will be apparent that my invention is by no means limited to the exact forms illustrated or the use indicated, but that many variations may be made in the particular structure used and the purpose for which it is employed without departing from the scope of my invention as set forth in the appended claims.

What I claim as new is:

1. A high frequency apparatus including a first drum-shaped cavity resonator comprising a pair of closely spaced planar conductors positioned in face-to-face relation and forming boundaries of said first cavity resonator between them, means comprising a pair of elongated coaxial conductors extending at right angles to said planar conductors and forming boundaries of a second cavity resonator contiguous with the first cavity resonator, the maximum transverse dimension of said coaxial conductors being substantially smaller than that of said planar conductors and an electron discharge device extending within said first cavity resonator and having a cathode, grid and another electrode, said first resonator being coupled between said grid and other electrode, and said second resonator coupled between said cathode and grid.

2. A high frequency apparatus including a pair of oppositely disposed apertured disc-like conductors connected at their outer edges to form boundaries of a drum-shaped first cavity resonator, an electron discharge device extending within said first cavity resonator and having a cathode, grid and another electrode, said grid and other electrode being connected to said disc-like conductors, and a coaxial-line second cavity resonator comprising a pair of axially elongated concentric conductors coaxial with said disc-like conductors, said concentric conductors being connected together at one end and connected to said grid and said cathode at the other end.

3. A high frequency apparatus including an envelope containing a cathode, grid and another electrode in the order named, a first drum-shaped cavity resonator surrounding said envelope and coupled between said grid and other electrode and comprising a pair of oppositely disposed plate-like members closed at their peripheries by a conducting collar and providing an output resonator, and a second resonator coupled between said cathode and grid and comprising an elongated coaxial line including an outer tubular member coupled to one of said plate-like members and an inner tubular member coaxial with said outer tubular member and coupled to said cathode and providing an input resonator, said outer and inner tubular members having a maximum transverse dimension of the order of one-half that of said plate-like members.

4. A high frequency apparatus including an

envelope containing a cathode, grid and another electrode in the order named, a first cavity resonator surrounding said envelope and coupled between said grid and other electrode and comprising a pair of oppositely disposed plate-like members closed at their peripheries by a conducting collar and providing an output resonator, and a second resonator coupled between said cathode and grid and comprising an elongated coaxial line including an outer tubular member coupled to one of said plate-like members and an inner tubular member coaxial with said outer tubular member and coupled to said cathode, and providing an input resonator and conducting means coupling said resonators together for providing feedback from the output resonator to the input resonator, said outer and inner tubular members having a maximum transverse dimension substantially smaller than that of said plate-like members.

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