April 30, 1946. A. V. HAEFF 2,399,223

ELECTRON DISCHARGE DEVICE

Filed Jan. 18, 1941 5 Sheets-Sheet 1

Fig. 1

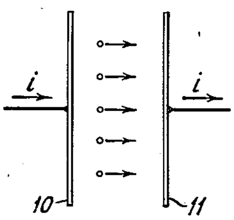


Fig. 2

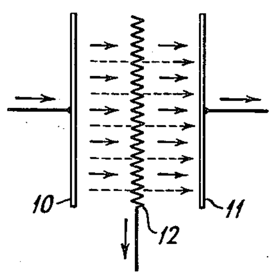


Fig. 5

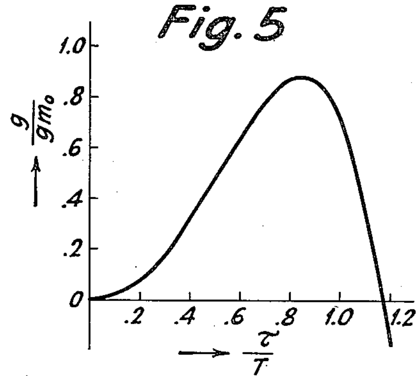


Fig. 3

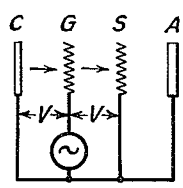


Fig. 4

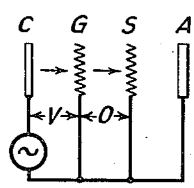


Fig. 6

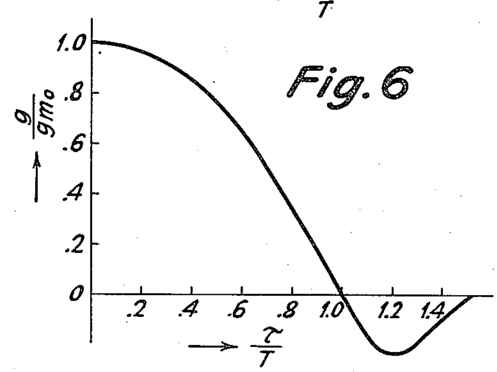


Fig. 9

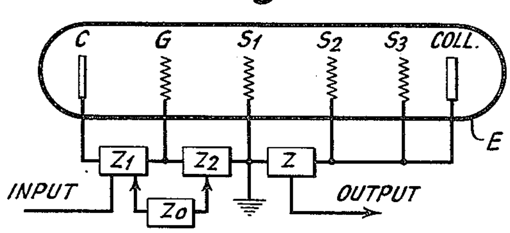


Fig. 7

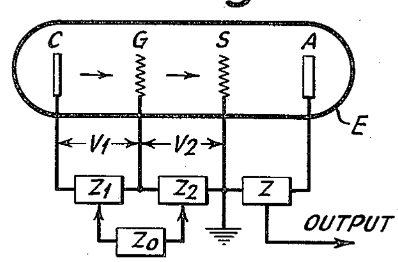


Fig. 10

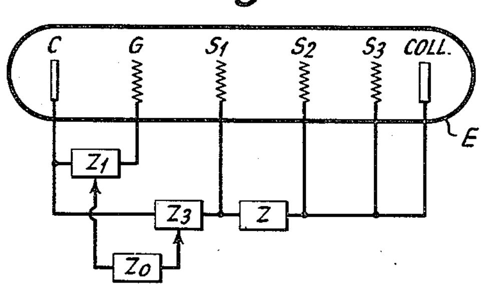
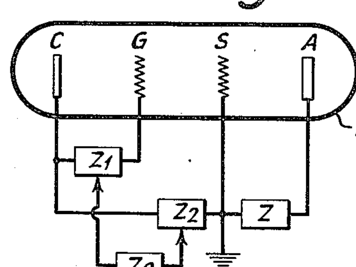


Fig. 8



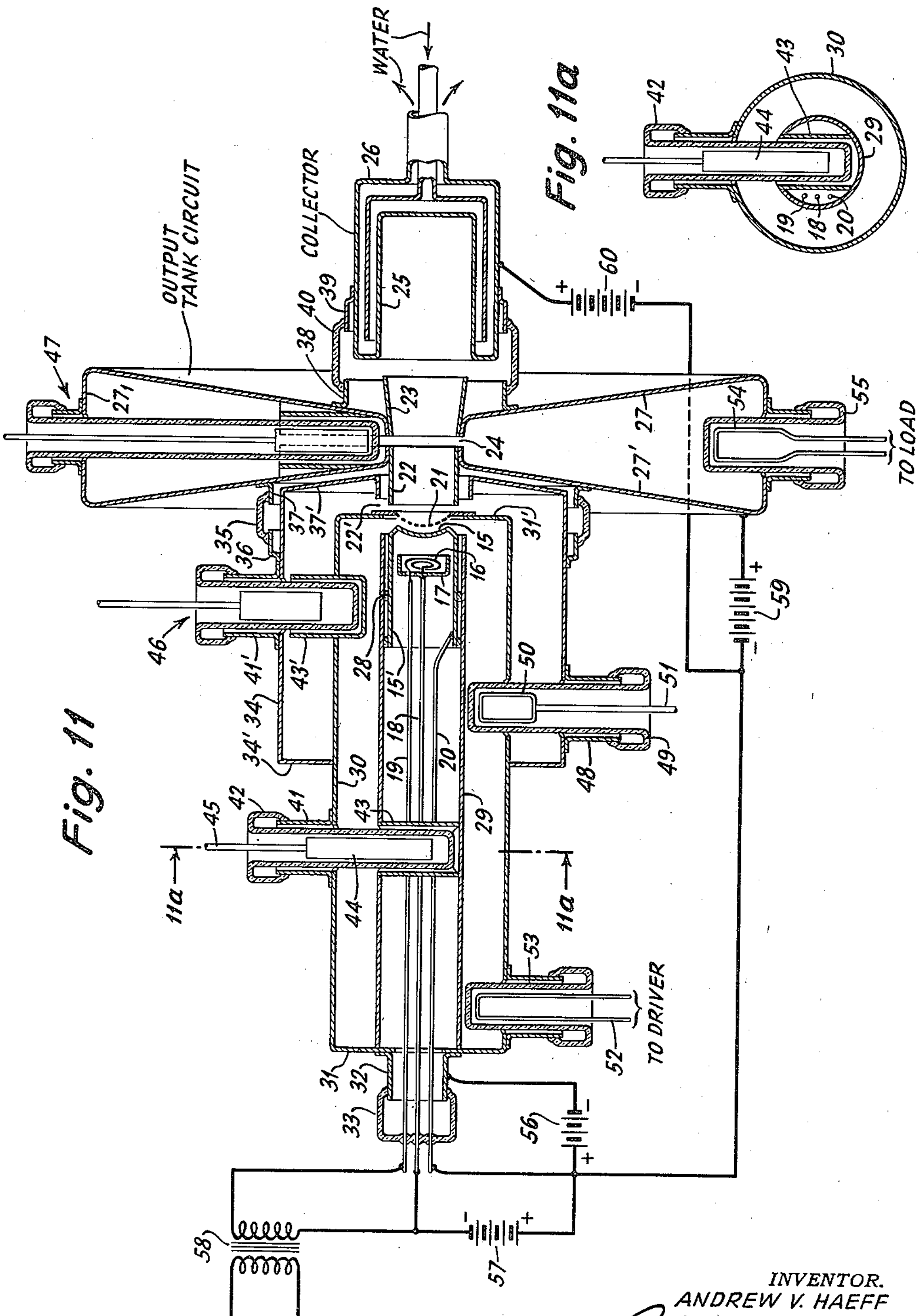
INVENTOR.
ANDREW V. HAEFF

BY Charles McClair
ATTORNEY.

April 30, 1946. A. V. HAEFF 2,399,223

ELECTRON DISCHARGE DEVICE

Filed Jan. 18, 1941 5 Sheets-Sheet 2



INVENTOR.
ANDREW V. HAEFF
BY Charles McClair
ATTORNEY.

April 30, 1946. A. V. HAEFF 2,399,223

ELECTRON DISCHARGE DEVICE

Filed Jan. 18, 1941 5 Sheets-Sheet 3

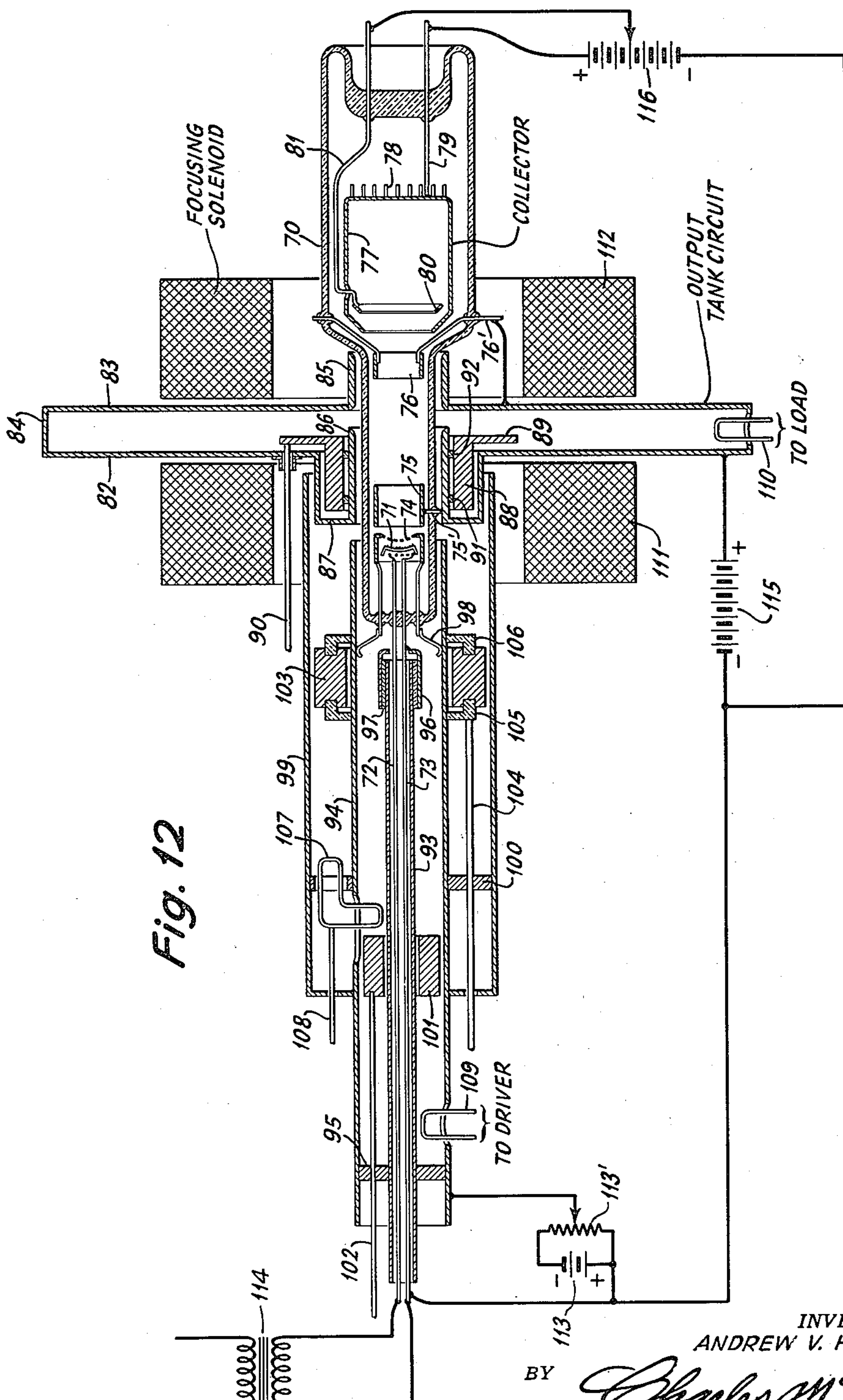


Fig. 12

INVENTOR.
ANDREW V. HAEFF

BY Charles McClair
ATTORNEY.

April 30, 1946. A. V. HAEFF 2,399,223

ELECTRON DISCHARGE DEVICE

Filed Jan. 18, 1941 5 Sheets-Sheet 4

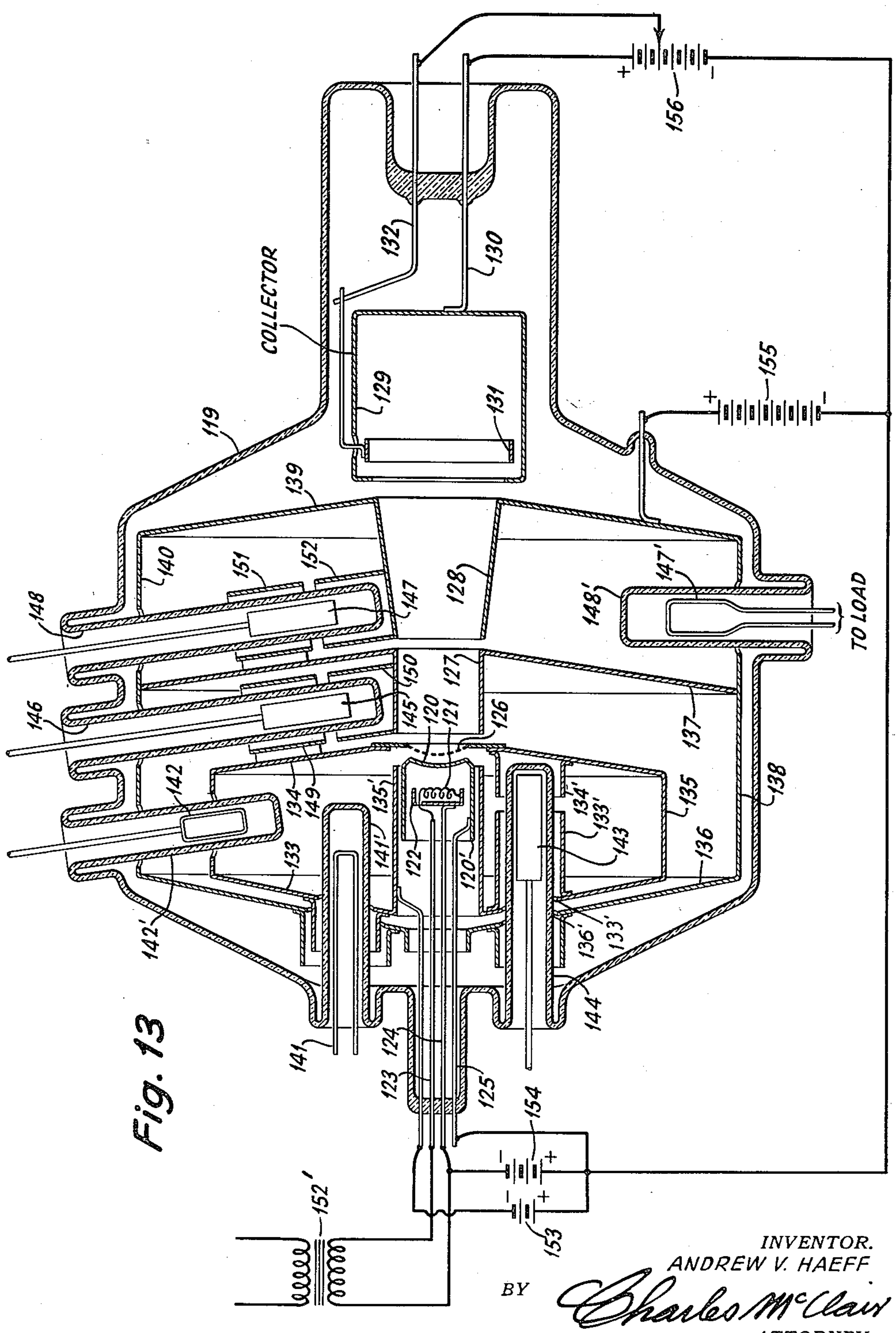


Fig. 13

INVENTOR.
ANDREW V. HAEFF
BY Charles McClair
ATTORNEY.

April 30, 1946. A. V. HAEFF 2,399,223

ELECTRON DISCHARGE DEVICE

Filed Jan. 18, 1941 5 Sheets-Sheet 5

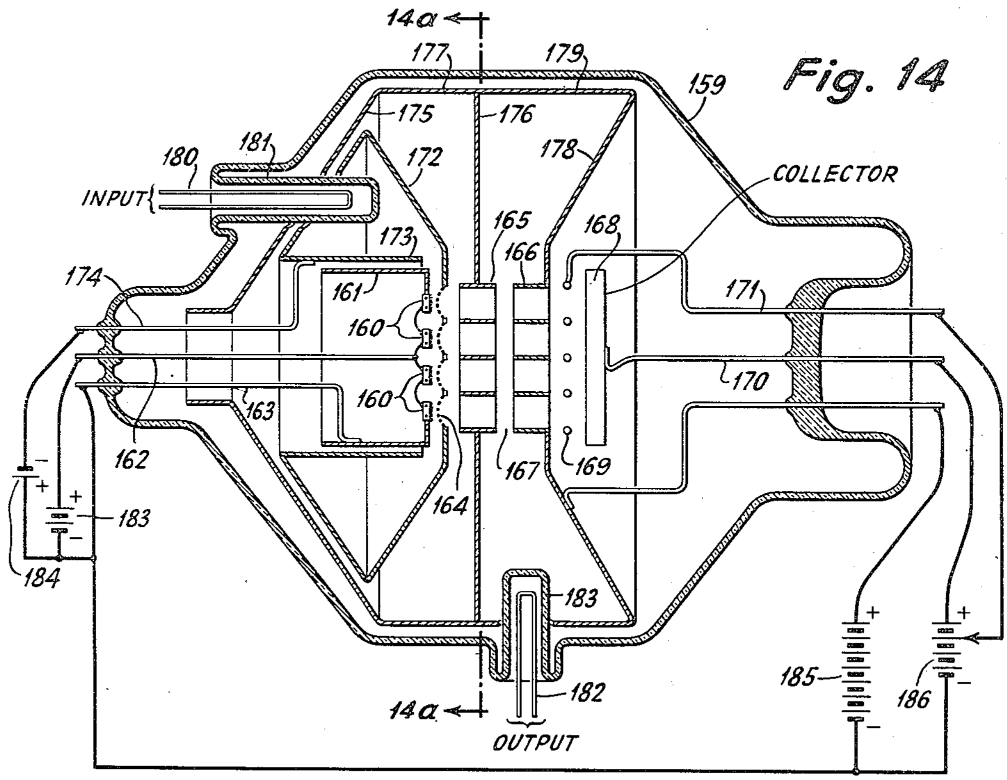


Fig. 14

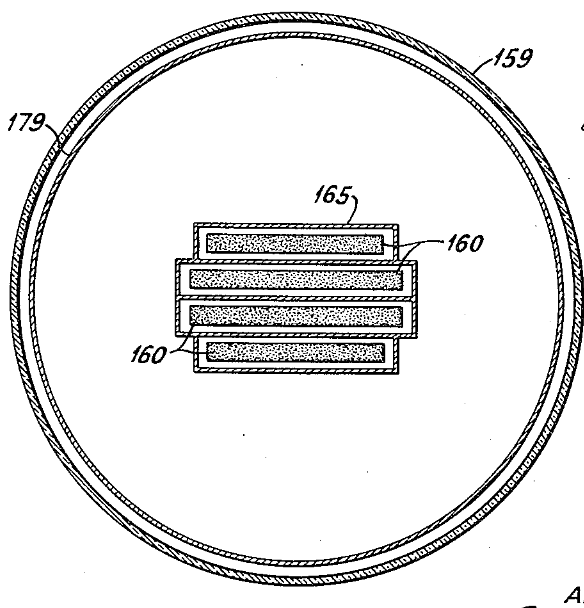


Fig. 14a

INVENTOR.
ANDREW V. HAEFF

BY Charles McClair
ATTORNEY.

Patented Apr. 30, 1946 2,399,223

UNITED STATES PATENT OFFICE

2,399,223

ELECTRON DISCHARGE DEVICE

Andrew V. Haeff, East Orange, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 18, 1941, Serial No. 375,029

50 Claims. (Cl. 250—27.5)

My invention relates to electron discharge devices and associated circuits having improved operating characteristics and particularly suitable for use at ultra-high frequencies.

It has been demonstrated that tubes utilizing conventional grids for controlling current are well adapted for operation at ultra-high frequencies and retain their characteristic advantage of possessing high transconductance. However, one of the difficulties encountered in operating amplifying tubes at ultra-high frequencies is the presence of considerable loading in the input circuit which results in an excessive amount of power being required to drive the tube. This decreases the effective power gain of the tube when operated as an amplifier.

The fundamental causes of high input loading are: (1) Ohmic and radiation resistance losses due to high circulating currents in electrodes and leads; (2) electron loading which results from the interaction of the electron stream with the circuit, including degenerative or regenerative effects caused by lead impedance.

In order to reduce ohmic resistance losses it is necessary to use internal leads and external conductors made of high conductivity material and having large peripheries. In addition inter-electrode capacitances must be reduced as much as possible in order to minimize circulating currents. To reduce radiation losses a thoroughly shielded circuit of conventional design or closed type "cavity" resonators must be used.

The principal object of my invention is to provide an electron discharge device and associated circuit having means for substantially reducing or completely neutralizing electron loading when the device is used at ultra-high frequencies.

It is also an object of my invention to provide an electron discharge device having means for minimizing ohmic and radiation resistance losses when the device is used at ultra-high frequencies.

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 Figures 1 and 2 are diagrammatic representations of electrodes and the movement of electrons between the electrodes; Figures 3 and 4 are diagrammatic representations of conventional tubes and methods of operating the same; Figures 5 and 6 are curves representing the relationship of the electron loading (conductance) and the transit time of the electrons of the tubes in Figures 3 and 4; Figures 7 to 10 inclusive are diagrammatic representations of tubes and circuits made according to my invention for practicing my invention; Figure 11 is a longitudinal section of an electron discharge device made according to my invention; Figure 11*a* is a section taken along the line 11*a*—11*a* of Figure 11; Figures 12, 13 and 14 are longitudinal sections of modifications of an electron discharge device made according to my invention; and Figure 14*a* is a section taken along the line 14*a*—14*a* of Figure 14.

In order to understand better the effect of electron loading, the mechanism of interaction between the electron stream and the electrodes to which circuits may be connected will be reviewed. Consider a system of two electrodes 10 and 11 as shown in Figure 1. Assume that electrons travel from the electrode 10, which may be a cathode, to the electrode 11, which may be an anode. During electron transit an image charge appears on the electrodes equal in magnitude to the total charge present at any moment within the interelectrode space. The division of the image charge between the two electrodes depends, in general, upon the instantaneous distribution of charges moving within the interelectrode space and upon the configuration of the electrodes. The current induced in an electrode due to motion of a charge is equal to the rate of time variation of the induced image charge on the electrode due to the moving charge. The total instantaneous current induced in the electrode by the electron stream will be found by summing the individual currents induced by all charges moving within the interelectrode space. If a voltage exists between electrodes 10 and 11 the displacement current due to the interelectrode capacitance must be also taken into account.

Consider now a three-electrode system formed, for example, by a cathode 10, a control grid 12 and the plate 11 of a triode. Two spaces have to be considered. The total current induced in the intermediate electrode 12 (Figure 2) is contributed by moving charges in both spaces, 10—12 and 12—11, and the total current is equal to the vector sum of the two currents. The power generated or absorbed by the electron stream within the spaces 10—12 and 12—11 depends upon the respective current, voltage and the phase angle between the current and voltage in each space. Thus the power generated or absorbed within the spaces 10—12 and 12—11, will be:

$$W_{10-12}=i_{10-12}\,V_{10-12}\cos\varphi_{10-12}$$
$$W_{12-11}=i_{12-11}\,V_{12-11}\cos\varphi_{12-11}$$

In a more general case, such as a low-μ triode, when there may exist considerable penetration of of the electric fields from space 12—11 into space 10—12, one must also consider direct-interaction between electrodes 11—10, so that a power $W_{10-11}=i_{10-11}\,V_{10-11}\cos\varphi_{10-11}$ also must be taken into account.

In order to reduce the electron loading the total power must be reduced to a minimum. This can be accomplished by choosing currents, voltages and their respective phases in such a way that the total power $W=W_{1-2}+W_{2-3}+W_{3-1}+\ldots$ is a minimum.

In a conventional negative grid tetrode operated at low frequencies the input electrode loading will be negligibly small if the driving voltage is applied in a conventional manner between the grid and the cathode so that the voltage also appears between the control grid G and the screen S. (See Figure 3.) The R.-F. electronic current passing in the G—S space is very nearly equal and opposite in phase to the current in the C—G space so that the total driving power is very nearly zero ($W=iV_{C-G}-iV_{G-S}\approx 0$). However, in a circuit shown in Figure 4 where the driving voltage is applied between the grid and the cathode only, but does not appear between the grid and the screen, the loading will be very severe at low frequencies. This loading is due to the fact that even though a current, equal to C—G space current, flows in the G—S space, no voltage is present in this region and hence no negative power is developed in the G—S space to balance the power absorbed in the C—G space.

As the driving frequency is increased the circuit of Figure 3 will exhibit electron loading which initially will increase with frequency. This loading is due to the fact that with increasing electron transit time with respect to a period of the driving frequency the amplitudes and phases of currents in the C—G and G—S spaces change in such a manner that the amounts of power absorbed and generated in the two spaces no longer balance each other. For the case of a high-μ control grid when the spacings and D. C. voltages are such that the G—S electron transit time is negligible compared to C—G transit time an analysis shows that the electron loading (conductance) will vary with transit time as shown in Figure 5. Here the ordinates of the curve represent the ratio G/Gmo where G=conductance of the grid G due to electron motions and Gmo=transconductance of the grid G at very low or zero frequency, that is when the transit time of the electron is negligible in comparison to the time of one cycle of the frequency of the applied voltage. The abscissae represent the ratio τ/T, that is the ratio of the transit time of the electron to the period of oscillation of the applied alternating voltage. The electron loading increases rapidly with transit time, reaches a maximum at the value of transit time τ equal to 0.85 of the oscillation period T and then, under ideal conditions, passes through zero and becomes negative. In the case of circuit shown in Figure 4 the variation of electron loading with transit time will be as shown in Figure 6. Starting with its maximum value at low frequency the loading decreases with increasing frequency.

These curves indicate that for certain values of electron transit angle, that is for certain values of the ratio of

$$\frac{\tau}{T}=\frac{\text{transit time}}{\text{period of oscillation}}$$

the loading will be small even for conventional input circuits. However, the values of frequency and operating voltages for these optimum conditions frequently lie outside the useful operating range of the tube. The tubes could be designed for this optimum condition but, in general, this may necessitate a compromise, so that high transconductance may be partly sacrificed. The present invention provides means for neutralizing electron loading for a wide range of frequencies and operating voltages without any sacrifice of the useful characteristics of the tube, such as high transconductance.

A general scheme is that in addition to the driving voltage applied between the cathode and grid, a voltage is developed between the control grid and the screen of such a magnitude and phase as to generate power in the grid-screen space and this power is fed back into the cathode-grid circuit, so that it will balance the power absorbed in the cathode-grid space.

A schematic diagram of such a circuit is represented in Figure 7. An impedance Z_2 is introduced between the screen S and the grid G of such magnitude and phase angle that the current i_{G-S} will produce a voltage V_2 across this impedance. The power $W_2=i_{G-S}V_2\cos(i_{G-S}V_2)$ generated in the G—S space is then fed to the grid-cathode circuit Z_1 by means of a coupling circuit Z_0. The impedances Z_1 and Z_2 usually take the form of tuned circuits and the coupling impedance Z_0 may be the inter-electrode capacitance or an auxiliary coupling element.

A modification of the circuit shown in Figure 7 is represented schematically in Figure 8, where the impedance Z_2 is shown introduced between the screen S and the cathode C rather than between the screen S and the control grid G. The coupling between the circuits Z_1 and Z_2 is provided by the control grid to screen capacitance or it can be suplemented by an auxiliary coupling circuit Z_0. In Figures 7 and 8 conventional output circuits with output impedances (Z) connected between the anode and the screen are shown. However, other types of output circuits can be used, since the input loading neutralization scheme here proposed in no way depends upon the extraction of energy from the output circuit.

Figure 9 shows schematically the input loading neutralization circuit in combination with an inductive type output circuit. Here the output circuit is connected between the two screening electrodes S_1 and S_2. The suppressor and current collecting electrodes, represented respectively by S_3 and coll., are also shown. Figure 10 represents schematically the input circuit arrangement of Figure 8 in combination with the inductive-output circuit. In the above circuit diagrams only the essential R. F. circuits are indicated. Blocking, grounding and by-passing condensers which are used for providing isolation of electrodes for D. C., so that different D. C. voltages can be applied to different electrodes, are not shown.

One practical embodiment of my invention incorporated in a so-called "inductive output tube" is shown in detail in Figure 11. "Inductive output tubes" and their operation are described more fully in my United States Patent 2,237,878, issued April 8, 1941, and assigned to the Radio Corporation of America. Briefly this tube comprises a cathode for supplying a beam of electrons and a collector for receiving the electrons. A modulating grid is placed adjacent the cathode for modulating the beam of electrons which passes to the collector. Surrounding the beam path is a resonant cavity circuit or cavity resonator comprising a hollow member having a passageway extending therethrough through which the beam passes. The passageway is provided with a gap lying in a plane transverse to the beam path. As the modulated beam of electrons passes across this gap, energy is transferred from the beam to the resonant cavity circuit which provides the output circuit for the tube and which can be coupled to a radiator or to an amplifier.

Referring to Figure 11, the tube is provided with a concave surface cathode 15 which can be made of tantalum. This cathode is heated by electron bombardment from an auxiliary cathode 16 made for example in the form of a tungsten spiral and surrounded by a focusing shield or cup 17 for directing the electrons from the filament to the cathode 15. The cathode spiral 16 is supplied with heating current by means of leads 18 and 19 and the main cathode 15 is supported at the end of a tubular member 15' to which the cathode lead 20 is electrically connected. The electron beam is modulated by means of the grid 21 and passes through a pair of screen and accelerating tubular electrode members 22 and 23 separated by gap 24 and the electrons are collected by means of a collector electrode 25 which is provided with a cooling jacket 26 for cooling the collector. The accelerating and screening electrodes 22 and 23 are cylindrical and conically shaped to avoid absorbing electron current from the beam which may tend to spread. The output circuit is of the closed resonant cavity type and is formed by two conically shaped metal surfaces 27 and 27' joined at the periphery by a short cylindrical section 27_1. The gap in the resonant cavity registers with the gap between the accelerated electrode members 22 and 23 to which the conically shaped sides of the resonant cavity are secured and electrically connected.

In order to practice my invention the cathode 15 is mounted in the supporting tubular member 29 of cylindrical form, a collar 28 of insulating material serving to insulate the tubular cathode extension 15' from the tubular member 29 but permitting capacity coupling therebetween. Thus the leads for the heater and cathode are shielded by means of the tubular member 29 which serves as the inner member of a concentric line circuit. The control grid 21 is supported at the end of a tubular member 30 of cylindrical form surrounding and coaxial with the inner tubular member 29 to form the outer portion of the concentric line circuit, the ends being closed by disc members 31 and 31'. The cathode grid circuit is formed by the tubular members 29 and 30 which constitute the inner and outer conductors of a concentric line shorted by the closure disc 31. This cathode-grid circuit, which may be referred to also as a resonant cavity tank circuit, corresponds to impedance Z_1 of Figure 9. The large capacitance between the cathode support or extension 15' and cylindrical member 29 serves to by-pass radio frequency current from the cathode to the tubular member 29.

The closure member 31 is provided with an aperture through which the lead wires 18, 19 and 20 extend and a collar or extension 32 to which the insulating cup-shaped member 33 is sealed and through which the conductors pass and are sealed. The cup-shaped member 33 hermetically seals the interior of the circuits.

A third tubular member 34 of cylindrical form is coaxial with and surrounds the other two tubular members. It is provided with closure members 34' and 37', a gap 22' being provided between the closure member 37' of tubular member 34 and closure member 31' of tubular member 30. The space between the cylinders 30 and 34 forms a resonant space which provides an impedance equivalent to Z_2 shown in Figure 9 between the control grid and accelerating or screen electrode 22.

To provide an insulating support between the accelerating and screen electrodes 22 and 23 to which a high positive voltage is applied in operation and the grid 21 to which a negative bias is applied, the cylinder 34 is supported on the wall of the tank circuit by the insulating glass cylinder or collar 35 sealed to the cylindrical collar members 36 and 37 supported on the cylindrical member 34 and the wall 27' of the tank circuit respectively. High capacitance between the end portion 37' of the cylindrical member 34 and the adjacent wall of the tank serves to by-pass high frequency circulating current so as to reduce the radio frequency potentials between the tubular member 34 and the wall of the tank to a negligible value. The collector 25 is supported in like manner from the other wall of the tank circuit to which is attached the collar extension 38, the collector cooling jacket being provided with collar extension 39, both sealed to the insulating cylindrical member or collar 40.

Independent tuning of all circuits is provided by means of plunger type condensers, for example the outer tubular member 30 is provided with a collar or extension 41 surrounding an aperture in the outer surface of the tubular member. Sealed to this extension is a re-entrant insulating tube 42 extending through this aperture and an aperture in the inner tubular member 29 provided with the extension 43 surrounding the aperture. This re-entrant glass tube is preferably made of low loss glass or of quartz. The tuning plunger 44 is inserted within the re-entrant insulating tube and may be adjusted by means of the insulating rod 45 attached to the plunger. Varying the position of the plunger changes the capacitance between the adjacent circuit elements and thus affords a means for tuning of the internal circuits. For tuning the screen circuit the same kind of arrangement is provided at 46, the tubular member 34 being provided with an aperture around which extends collar 41', the re-entrant glass tubing extending within the cup-shaped extension 43' in the tubular member 30. A like arrangement is shown generally at 47 in the tank circuit.

The coupling between the cathode-grid and grid-screen circuits, which coupling corresponds to impedance Z_0 in Figure 9, is provided by means of closed loop 50, the position of which is adjustable by means of adjusting rod 51. An extension 48 on the outer tubular member 34 surrounds an aperture into which a re-entrant glass portion 49 extends through a registering aperture in the tubular member 30. The position of the closed loop 50 determines the degree of coupling.

The driving power to the grid-cathode circuit is supplied from an R.-F. generator by means of a loop 52 extending within a re-entrant portion 53 positioned within an aperture in the outer surface of tank member 30. The output from the tank circuit is obtained by means of a loop 54 extending within a re-entrant glass portion 55 supported by the tank circuit and extending through an aperture in the tank circuit.

The outer tubular member 29 is biased negatively with respect to the cathode 15 by means of a voltage source 56. The voltage source 57 places the cathode 15 at a higher voltage than the heating filament 16 so that electrons will bombard the back of the cathode. The heating current for the filament is supplied by potential source 58. The tank circuit is maintained at a highly positive potential with respect to the cathode by means of potential source 59 which may be greater than the potential source 60 connected between the collector and the cathode.

In operation the input voltage is applied through the loop 52 to the cathode grid tank circuit including tubular member 29 and 30. This causes the grid 21 to modulate the electron stream from the cathode 15. This modulated beam of electrons passes by the gap 22′ in the screen-control grid circuit delivering energy to the resonant cavity circuit consisting of the cylinders 30 and 34, which energy is fed back by means of loop 50 in order to minimize the amount of driving power. The modulated stream then passes through the accelerating electrode 22, past the gap 24 to energize the output tank circuit 27, 27′, 27_1, the decelerated electrons being absorbed by the collector 25 at a lower velocity. The output is obtained from the tank circuit by means of the loop 54 extending within the tank circuit.

It will thus be apparent that by means of the construction shown in Figure 11 that losses due to the electron loading effects in the input circuit are reduced to a minimum by my invention. Ohmic and resistance losses due to high circulating current in electrodes and leads are reduced to a minimum due to the fact that concentric lines and resonant cavities used are of high conductivity material and large diameter and due to the effective by-passing of the radio frequency currents. Radiation losses are reduced to a minimum because of the shielded circuits. Thus all three objects contemplated by my invention are practiced to provide a tube particularly suitable for use at ultra-high frequencies at high efficiencies.

In Figure 12 is shown a longitudinal section of a modification of my invention in which all of the resonant cavity circuits are placed outside the evacuated envelope 70. The concave spherically curved cathode 71, which is indirectly heated, is provided with heater leads 72 and 73, lead 73 serving also as the lead for the cathode. A control grid 74 is positioned closely adjacent the cathode and has the same configuration, the accelerating screen and electrodes 75 and 76 being supported from the glass envelope by means of leads 75′ and 76′. The collector 77 is provided with the radiating fins 78 and the lead and support wire 79. A secondary electron suppressor 80 is positioned within the collector adjacent the mouth of the collector and acts to suppress secondary electrons generated within the collector. The tank circuit comprises a pair of flat circular metal discs 82 and 83 connected together at the periphery by means of the ring-shaped member 84. The output gap is formed between the two electrodes 85 and 86 connected to and electrically supported by the disc-shaped side members of the tank circuit, the side 82 being provided with an annular extension 87 into which the cylinder or collar 88 is slidably fitted to provide a tuning condenser for the tank circuit, the collar being provided with a radially extended lip 89 and adjusted by means of insulating rod 90 on the side of the tank circuit. The condenser cylinder is slidably supported on the electrode 86 by means of the insulating collar members 91 and 92.

The cathode-grid concentric line circuit comprises inner tubular member 93 which serves to shield the cathode leads and the outer tubular member 94 coaxial with and concentric with the inner tubular member 93, the shorting disc 95 electrically connecting the two tubular members. The cathode is capacitively coupled to the inner tubular member by means of the cup-shaped extension 96 electrically connected to the cathode lead and insulatingly supported on the inner tubular member by means of the insulating collar 97. The grid is electrically connected to the outer tubular member by means of the spring contacts 98. The resonant cavity for the screen electrode-grid circuit is provided by means of the outer tubular member 99 coaxial with and surrounding member 94 and shorted by means of the disc-shaped member 100. The screen electrode-control grid circuit is tuned by means of the cylinder 103 provided with the adjusting rod 104 and slidably supported on tubular member 94 by means of the insulating ring-shaped members 105 and 106. To feed back energy from the screen grid-control grid circuit to the cathode-control grid circuit, I provide an L-shaped loop member 107 extending from the space between members 94 and 99 through an aperture into the interior of tubular member 94. Adjustment is provided by means of the rod 108. To couple the cathode-grid circuit to a driver, a loop 109 is provided extending through an aperture in the tubular member 94. The output from the output tank circuit is obtained by means of the loop 110 extending within the aperture in the member 84 of the tank circuit. To focus the electron beam through the tube, solenoids 111 and 112 are provided for producing a magnetic field in the direction of the tube axis.

The grid bias voltage is obtained from the voltage source 113 through a voltage divider 113′, the cathode heating circuit being provided by means of transformer 114 connected to a voltage source. The tank circuit is maintained at a highly positive potential with respect to the cathode by means of voltage source 115 which may be greater than voltage source 116 provided with the collector.

The operation of this device is substantially the same as that shown in Figure 11.

A further modification of my invention is shown in Figure 13 which is provided with envelope 119 in which all of the electrode and circuit elements are enclosed. The cathode 120 of concave-shape is bombarded by means of electrons from cathode filament 121 surrounded by the cup-shaped focusing and shielding member 122, leads 123 and 124 being provided for the heating of filament 121, and lead 125 being provided for the cathode. The grid 126 is placed closely adjacent the cathode and the electron beam travels through successive accelating electrodes 127 and 128 to the collector 129 supported on the lead 130 and provided with the suppressor ring 131 provided with the lead 132.

The cathode-grid tank circuit comprises the slightly curved disc-shaped sides 133 and 134 electrically connected at their peripheries by means of ring-shaped member 135, the inner part of the circuit being provided with the tubular extension 135′, which is capacitively coupled to the cathode extension 120′, the side 134 supporting the grid 126. The screen electrode-control grid resonant cavity comprises the side wall members 136 and 137 connected at their peripheries by means of the ring-shaped member 138. Thus a second resonant cavity is provided surrounding the resonant cavity of the cathode-control grid circuit. The accelerating or screen electrode 127 is secured to the wall 137 of the screen electrode-control grid circuit. The resonant cavity output circuit comprises the side wall 137, the side wall 139 and the outer ring member 140 connected at the peripheries. The ring members 140 and 138 could of course be extensions of each other. The accelerating electrode 128 is connected to and supported by the end wall 139.

A coupling and tuning of the circuits is permitted in the same manner as in the other modifications of the applicant's invention, that is the envelope is provided with a number of re-entrant portions extending through apertures in the various tank circuits and providing passageways for coupling loops or tuning condensers. The driver circuit is coupled to the grid-cathode circuit by loop 141 extending within re-entrant portion 141'. The screen electrode-control grid tank circuit and the control grid-cathode tank circuit are inductively coupled to permit feedback by means of the loop 142 within extension 142'. This loop is mounted within the re-entrant portion 142' of the envelope extending through apertures in the two tank circuits. Tuning of the cathode-control grid tank circuit is accomplished by means of the tuning plunger 143 slidably mounted within the re-entrant tube 144 extending through apertures 136' and 133'' in the tank circuits and the extensions 133' and 134' between which is provided a gap. Tuning of the screen electrode-control grid circuit is accomplished by means of the tuning plunger 145 mounted within the re-entrant glass tube 146. The plunger 145 enters a tubular member 149, which is attached to member 134, and also projects into a tubular well 150 connected to the electrode 127. A similar arrangement is provided for tuning the output circuit, the plunger 147 being slidably supported within the re-entrant tube 148 and coupling extensions 151 and 152. The output is delivered by means of the loop 147' mounted within the extension 148', which extends through an aperture in the ring-shaped connecting member 140 of the output tank circuit. Heating current is supplied by means of potential source 152' and potential difference for causing bombardment of the rear surface of the cathode 120 by voltage source 154. Grid bias is furnished by means of voltage source 153. The potentials required for the tank circuit and the collector are provided respectively by potential sources 155 and 156.

The operation of this form of my invention corresponds to that in the other modifications shown.

A still further modification of my invention is shown in Figures 14 and 14*a*. This modification is somewhat similar to the form shown in Figure 13, but is provided with a multi-element arrangement of cathode and grid and multi-cellular accelerating electrodes in order to reduce space charge and electron transit time effects. The principles by means of which space charge effects are reduced in multi-cellular beam devices is more fully set forth and claimed in my copending application Serial No. 323,071 filed March 9, 1940, and assigned to the same assignee as the present application. Briefly by providing a multi-cellular type arrangement the space charge effects are substantially eliminated by maintaining the space potential through the electrodes at a higher potential than would be the case where a single large beam of electrons is used.

In the arrangement here shown envelope 159 encloses the electrodes and tank circuits. The cathode comprises a plurality of cathode elements 160 provided with the supporting cup-shaped member 161 and heater and cathode leads 162 and 163. The grids 164 are of a multi-element type and the beams pass through multi-cellular accelerating electrodes 165 and 166 having passageways registering with the cathodes and grids, the electrons being collected by means of the collector 168 in front of which is mounted the suppressor 169. Leads 170 and 171 are provided, respectively, for the collector and the suppressor. The grid-cathode circuit 172 comprises a member formed by two truncated cones one of which supports on its interior a tubular extension 173 capacitively coupled to the cathode collar 161. The other cone supports grid 164. The screen electrode-control grid circuit comprises the wall members 175, 176 and 177, the wall 176 supporting the screening and accelerating electrode 165. The output tank circuit comprises the wall member 176, a conically shaped wall member 178, these being electrically connected at their peripheries by means of ring-shaped member 179 which can be formed as an extension of the member 177. The accelerating electrode 166 is supported by the wall member 178. The usual re-entrant glass tubular extensions are provided, the input loop 180 extending within the re-entrant portion 181, which in turn extends through the apertures in the circuits for the screen electrode-control grid tank and cathode-control grid tank. The output is delivered by means of a loop 182 extending within the re-entrant tubular member 183 extending within an aperture in the output tank circuit. Heating voltage is supplied by means of the voltage source 183 and grid bias by means of voltage source 184, the output tank voltage being provided by potential source 185 and the collector voltage by means of potential source 186. A section taken along line 14*a*—14*a* looking towards the cathode is shown in Figure 14*a*. The operation of this device is substantially the same as that of the other forms described. A coupling loop not shown, but which may be substantially like loop 42 in Figure 13, can be used for coupling the cathode grid and screen and accelerating electrode resonant cavity tank circuits 172 and 175.

It will be apparent from the above discussion and description that I have provided an electron discharge device particularly suitable for use at ultra-high frequencies since both ohmic and radiation resistance losses due to high radio frequency circulating currents in electrodes and leads have been substantially eliminated, and because electron loading, which results from interaction of the electron stream and the circuit, including regenerative or degenerative effects caused by lead impedance, has also been substantially neutralized. This is accomplished by means of leads and external conductors of highly conducting material and large diameter. The radiation losses are reduced to a minimum by thoroughly shielded circuits comprising closed type cavity resonators.

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. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a first impedance connected between said cathode and control electrode and a second impedance connected between said control electrode and said screen electrode, said second impedance being free of any direct inductive coupling with said first impedance, and means electrically coupling said impedances together, said last means being coupled only to said impedances for transferring energy only between said first impedance and said second impedance.

2. An electron discharge device having a cathode electrode for supplying a beam of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a first impedance connected between said cathode and control electrode, and a second impedance connected between said screen electrode and said control electrode, means electrically coupling said impedances together, and means intermediate said screen electrode and said collector for inductively extracting energy from the electron beam as it moves from said cathode to said collector.

3. An electron discharge device having a cathode electrode for supplying a beam of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a first impedance connected between said cathode and control electrode, and a second impedance connected between the control electrode and screen electrode, and means electrically coupling said impedances together, said means being coupled only to said impedances for transferring energy only between said second impedance to said first impedance, and means intermediate sa'd screen electrode and said collector for inductively extracting energy from the electron beam as it moves from said cathode to said collector.

4. An electron discharge device having a cathode electrode for supplying a beam of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector for modulating said beam of electrons and a screen electrode intermediate said control electrode and collector, a first impedance connected between said cathode and control electrode, and a second impedance connected between the control electrode and screen electrode, means electrically coupling said impedances together, said last means being coupled only to said impedances for transferring energy only between said second impedance to said first impedance, and a resonant cavity tank circuit surrounding the path of said beam between the control electrode and the collector for inductively abstracting energy from said beam.

5. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a tubular member electrically coupled to said cathode electrode, a first conducting member electrically coupled to said control electrode and said tubular member and forming with said tubular member a first tank circuit, a second conducting member electrically coupled to said screen electrode and said first conducting member and providing with said first conducting member a second tank circuit, and coupling means coupling said tank circuits together.

6. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a tubular member electrically coupled to said cathode electrode, a second tubular member surrounding said first tubular member and electrically coupled to said control electrode and forming with the first tubular member a first tank circuit, a third tubular member surrounding and electrically coupled to said second tubular member and said screen electrode and providing with said second tubular member a second tank circuit, and mean coupling said tank circuits together.

7. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a grid electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said grid and collector, a first conducting member electrically coupled to said cathode electrode, a second conducting member electrically coupled to said grid and surrounding said first conducting member and forming therewith a tank circuit, a third conducting member electrically coupled to said screen electrode and surrounding said second conducting member and providing therewith a second tank circuit, and coupling means coupling said tank circuits together, and other circuit means having a gap surrounding the electron stream between the cathode electrode and collector inductively extracting energy from said electron stream.

8. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a first tubular member electrically coupled to said cathode electrode, a second tubular member electrically connected to said control electrode and surrounding said first tubular member and forming therewith a concentric line circuit, an impedance electrically connected between said screen electrode and said second tubular member, and coupling means electrically coupling said concentric line circuit with said impedance.

9. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a first tubular member electrically coupled to said cathode electrode, a second tubular member electrically connected to said control electrode and

surrounding said first tubular member and forming therewith a concentric line circuit, an impedance electrically connected between said screen electrode and said second tubular member and including a third tubular member surrounding said second tubular member and coupling means electrically coupling said concentric line circuit with said impedance, and other circuit means between the screen electrode and collector for inductively extracting energy from said electron stream as it passes from the cathode electrode to the collector.

10. An electron discharge device having a cathode including an elongated cup-shaped member provided at its closed end with an emitting surface for providing a stream of electrons, a collector electrode for receiving electrons from said cathode, a cavity resonator surrounding said cathode and a grid supported adjacent the emitting surface of said cathode by said cavity resonator, said cavity resonator having a gap registering with the space between the cathode and the grid, an auxiliary electrode positioned between the grid and the collector and a cavity resonator coupled to said auxiliary electrode and to the first cavity resonator, and a third cavity resonator surrounding the electron discharge path between the cathode and collector and provided with a gap surrounding the discharge path intermediate the auxiliary electrode and the collector.

11. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector electrode for collecting said electrons, a control electrode intermediate said cathode electrode and said collector and a screen electrode intermediate said control electrode and collector, a cavity resonator coupled between the cathode electrode and control electrode, a second cavity resonator coupled between said control electrode and said screen electrode, and means electrically coupling said cavity resonators together, and a third cavity resonator having a passageway therethrough and provided with a gap surrounding the electron path between the screen electrode and the collector.

12. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate the cathode electrode and the collector for modulating the electrons, and a screen electrode intermediate said control electrode and collector, a first tubular member electrically coupled to the cathode electrode, and a second tubular member surrounding and coaxial with said first tubular electrode and electrically coupled to said control electrode and forming with said first tubular member a concentric line tank circuit, and a third tubular member electrically coupled to said screen electrode and surrounding and coaxial with the second tubular member and providing therewith a cavity resonator, and means coupling said cavity resonator with said concentric line circuit.

13. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate the cathode electrode and the collector for modulating the electrons, and a screen electrode intermediate said control electrode and collector, a first tubular member electrically coupled to the cathode electrode, and a second tubular member surrounding and coaxial with said first tubular electrode and electrically coupled to said control electrode and forming with said first tubular member a concentric line tank circuit, and a third tubular member coupled to said screen electrode and surrounding and coaxial with the second tubular member and providing therewith a cavity resonator, and means coupling said cavity resonator with said concentric line circuit, and a cavity resonator positioned between the screen electrode and the collector and having a passageway therethrough and surrounding the discharge path between the control electrode and cathode, said passageway being provided with a gap surrounding the electron path intermediate the screen electrode and the collector for inductively extracting energy from the stream of electrons.

14. An electron discharge device having a cathode for supplying a stream of electrons, said cathode including a tubular portion, a tubular member surrounding the tubular portion of said cathode and capacitively coupled thereto, a second tubular member coaxial and concentric with said first tubular member and forming therewith a coaxial line tank circuit, a grid supported by said second tubular member adjacent the cathode, an accelerating electrode and a collector for receiving said electrons, a tank circuit electrically coupled between said second tubular member and said accelerating electrode, means coupling said tank circuit with said coaxial line tank circuit and output means coupled to the electron stream for abstracting energy from said electrons.

15. An electron discharge device having a cathode for supplying a stream of electrons, said cathode including a tubular extension, a tubular member surrounding the tubular extension of said cathode and capacitively coupled thereto, a second tubular member coaxial and concentric with said first tubular member and forming therewith a coaxial line tank circuit, a grid supported by said second tubular member adjacent the cathode, an accelerating electrode and a collector for receiving said electrons, a cavity resonator electrically coupled between said second tubular member and said accelerating electrode, means coupling said cavity resonator with said coaxial line tank circuit and a cavity resonator inductively coupled to the electron stream between said grid and said collector for abstracting energy from said stream of electrons.

16. An electron discharge device having an elongated cup-shaped member provided at its closed end with an emitting surface for providing a cathode, a collector for receiving electrons from the cathode, a tubular member coaxial with and surrounding said cup-shaped member and capacitively coupled thereto, a second tubular member surrounding said first tubular member and forming therewith a concentric line tank circuit, a grid supported adjacent the cathode by said second tubular member, a third tubular member surrounding said second tubular member and providing therewith a first cavity resonator, a second cavity resonator provided with a gap surrounding the path of the electrons from the cathode to the collector, said second tubular member being provided with an aperture and a coupling loop extending through said aperture, said first and second tubular members being provided with registering apertures through which a capacity tuning plunger extends and said second and third tubular members having registering apertures through which a second tuning plunger extends, said second cavity resonator having an aperture and a coupling loop received within said last aperture.

17. An electron discharge device having a

cathode including an elongated cup-shaped member provided at its closed end with an emitting surface, a collector electrode for receiving electrons from said cathode, a tubular member coaxial with and surrounding said cup-shaped member and capacitively coupled thereto, a second tubular member surrounding said first tubular member and forming therewith a concentric line tank circuit, a grid supported adjacent the cathode by said second tubular member, a third tubular member surrounding said second tubular member and providing therewith a first cavity resonator, a second cavity resonator provided with a gap surrounding the path of the electrons from the cathode to the collector, said second tubular member being provided with an aperture, and a coupling loop extending through said aperture.

18. An electron discharge device having a cathode for supplying electrons and a collector for receiving said electrons, a tubular member coaxial with said cathode and electrically coupled thereto, a second tubular member surrounding said first tubular member and forming therewith a concentric line tank circuit, a grid supported adjacent the cathode and electrically connected to said second tubular member, a third tubular member surrounding said second tubular member and providing therewith a first cavity resonator, a second cavity resonator provided with a gap surrounding the path of the electrons between the cathode and the collector, said second tubular member being provided with an aperture, and a coupling loop positioned within said aperture.

19. An electron discharge device having a cup-shaped cathode having a surface for emitting electrons, a first tubular member surrounding said cup-shaped member and extending away from the emitting surface of said cathode, a second tubular member surrounding said first tubular member and connected at one end to said first tubular member, and an insulating cup-shaped member sealing the end of the first tubular member spaced from the emitting surface, a transverse closure member on the other end of said second tubular member and having an aperture registering with the emitting surface of said cathode and a grid supported within said aperture and positioned adjacent the cathode, a third tubular member surrounding said second tubular member and electrically connected thereto and forming with said second tubular member a cavity resonator, a pair of accelerating electrodes positioned adjacent said grid and separated by a gap, and a collector electrode for collecting electrons passing through said grid and said accelerating electrodes, a cavity resonator having a passageway extending therethrough and having a gap registering with said gap between said accelerating electrodes, and insulating means supporting said third tubular member in spaced relation from said last cavity resonator and sealing the space between the third tubular member and said last cavity resonator, and a second insulating member supporting the collector from the opposite side of said last cavity resonator and sealing the space between said last cavity resonator and the collecting electrode and providing an envelope for said cathode and collecting electrode.

20. An electron discharge device having a cathode provided with a surface for emitting electrons, a first tubular member coaxial with said cathode and extending away from the emitting surface of said cathode, a second tubular member surrounding said first tubular member and connected at one end to said first tubular member, and an insulating cup-shaped member sealing the end of said first tubular member spaced from the emitting surface, a transverse closure member on the other end of said second tubular member and having an aperture registering with the emitting surface of said cathode and a grid supported within said aperture and positioned adjacent the cathode, a third tubular member surrounding said second tubular member and electrically connected thereto and forming with said second tubular member a cavity resonator, a pair of accelerating electrodes positioned adjacent the grid and separated by a gap, and a collector electrode for collecting electrons which have passed through the grid and said accelerating electrodes, an output tank circuit comprising a cavity resonator having a passageway extending therethrough and having a gap registering with said gap between said accelerating electrodes, and insulating means supporting said third tubular member in spaced relation with said last cavity resonator and sealing the space between the third tubular member and said last cavity resonator, and a second insulating member supporting the collector from the opposite side of said last cavity resonator and sealing the space between said last cavity resonator and the collecting electrode and providing an envelope for said cathode and collecting electrode, said second and third tubular members being provided with registering apertures and a re-entrant insulating extension extending through said apertures, and a coupling member inserted within said extension, said second tubular member being provided with a second aperture and a re-entrant insulating tubular member extending within and sealing said second aperture and being adapted to receive an input coupling loop for applying an input voltage to the grid, said output tank circuit being provided with an aperture and a re-entrant insulating tubular member extending within the aperture and adapted to receive a coupling loop for extracting energy from the tank circuit.

21. An electron discharge device having an elongated envelope containing a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode and a screen and accelerating electrode positioned between the control electrode and collector electrode, said cathode, control electrode, accelerating electrode and collector electrode having leads extending through the envelope of the tube, a first tubular member adjacent the cathode end of the envelope and electrically coupled to said cathode, a second tubular member surrounding said first tubular member and electrically connected to said control electrode, said tubular members being electrically connected together and closed at one end and providing a coaxial line tank circuit for said control electrode and cathode, a third tubular member surrounding said second tubular member and electrically connected to said second tubular member and electrically coupled to said screen and accelerating electrode to provide a screen electrode tank circuit, and a tank circuit surrounding the electron path between the control electrode and collector electrode and having a gap transverse to the electron path, and means coupling the coaxial line tank circuit and the screen tank circuit together.

22. An electron discharge device having a

cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode and a screen and accelerating electrode positioned between the control electrode and collector electrode, a first tubular member adjacent the cathode electrically coupled at one end to said cathode, a second tubular member surrounding said first tubular member and electrically connected to said control electrode, said tubular members being electrically connected together to provide a coaxial line tank circuit for said control electrode and cathode, a third tubular members surrounding said second tubular member and electrically connected to said second tubular member and electrically coupled to said screen and accelerating electrode to provide a screen electrode tank circuit, and a tank circuit surrounding the electron path between the control electrode and collector electrode and having a gap transverse to the electron path, and means coupling the coaxial line tank circuit and the screen electrode tank circuit together, and a tuning condenser for the screen and accelerating electrode tank circuit comprising a conducting tubular member surrounding and movable longitudinally of said second tubular member.

23. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode and a screen and accelerating electrode positioned between the control electrode and collector electrode, a first tubular member adjacent the cathode electrically coupled at one end to said cathode, a second tubular member surrounding said first tubular member and electrically connected to said control electrode, said tubular members being electrically connected together to provide a coaxial line tank circuit for said control electrode and cathode, a third tubular member surrounding said second tubular member and electrically connected at one end to said second tubular member and electrically coupled to said screen and accelerating electrode at its other end to provide a screen electrode tank circuit, and a tank circuit surrounding the electron path between the control electrode and collector electrode and having a gap transverse to the electron path, and means coupling the coaxial line tank circuit and the screen and accelerating electrode tank circuit together, and a tuning condenser for the screen and accelerating electrode tank circuit comprising a conducting tubular member surrounding and movable longitudinally of said second tubular member, and a tuning condenser for the control electrode cathode tank circuit comprising a conducting tubular member surrounding and movable longitudinally of said first tubular member adjacent the cathode.

24. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode and a screen and accelerating electrode positioned between the control electrode and collector electrode, a first tubular member adjacent the cathode electrically coupled at one end to said cathode, a second tubular member surrounding said first tubular member and electrically connected to said control electrode, said tubular members being electrically connected together to provide a coaxial line tank circuit for said control electrode and cathode, a third tubular member surrounding said second tubular member and electrically connected at one end to said second tubular member and electrically coupled to said screen and accelerating electrode at its other end to provide a screen and accelerating electrode tank circuit, and means coupling the coaxial line tank circuit and the screen and accelerating electrode tank circuit together, and a tuning condenser for the screen and accelerating electrode tank circuit comprising a conducting tubular member surrounding and movable longitudinally of said second tubular member, and a tuning condenser for the control electrode-cathode tank circuit comprising a conducting tubular member surrounding and movable longitudinally of said first tubular member adjacent the cathode.

25. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode, a first tubular member adjacent the cathode and electrically coupled at one end to said cathode, a second tubular member surrounding said first tubular member and electrically coupled to said control electrode, said tubular members being electrically connected together to provide a coaxial line tank circuit for said cathode and control electrode, and a tuning means for said coaxial line tank circuit including a conducting member within said second tubular member and surrounding and slidable longitudinally of said first tubular member, and a tank circuit surrounding the electron path between the control electrode and collector electrode and having a gap transverse to the electron path.

26. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode, a first tubular member adjacent the cathode and electrically coupled at one end to said cathode, a second tubular member surrounding said first tubular member and electrically coupled to said control electrode, said tubular members being electrically connected together to provide a coaxial line tank circuit for said cathode and control electrode, and a tuning means for said coaxial line tank circuit including a conducting member within said second tubular member surrounding and slidable longitudinally of said first tubular member.

27. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode and a pair of screen and accelerating electrodes positioned between the control electrode and collector electrode and comprising tubular members surrounding the electron path between the control electrode and collector electrode, said tubular electrodes being spaced apart and providing a gap, and a cavity resonator surrounding the electron path between said screen and accelerating electrodes and having walls connected to said screen and accelerating electrodes, one of said walls being provided with an axially extending chamber, surrounding one of said screen and accelerating electrodes and a tuning condenser for said cavity resonator including a tubular member within said chamber and surrounding and movable longitudinally of said screen and accelerating electrode.

28. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving electrons, a control electrode adjacent the cathode and a cavity resonator surrounding the electron path between the control electrode and the collector electrode, said cavity resonator comprising a pair of spaced flat wall members having registering apertures through

which the discharge from the cathode to the collector takes place and conducting means electrically connecting said wall members together at their peripheries to form a cavity resonator, one of said wall members being provided with a hollow flange extending outwardly therefrom and forming a hollow chamber surrounding the electron path and a collar of conducting material provided with a flange parallel to the surface of the wall member and positioned within and movable longitudinally of said hollow flange and providing a tuning plunger for said cavity resonator.

29. An electron discharge device having an envelope containing a cathode for supplying electrons and a collector for receiving said electrons, a control electrode adjacent the cathode for modulating said electrons and a pair of screen and accelerating electrodes positioned between the control electrode and collecting electrode and spaced apart and providing a gap therebetween, a first cavity resonator electrically coupled to said control electrode and to said cathode and providing an input circuit, a second cavity resonator electrically coupled to one of said screen and accelerating electrodes and to the cathode control electrode cavity resonator, and an output cavity resonator electrically coupled between said screen and accelerating electrodes, said cavity resonators being provided with apertures, and re-entrant tubular portions of said envelope extending through said apertures within said cavity resonators, one of said re-entrant portions being adapted to receive a coupling loop for coupling two of said cavity resonators together, and other re-entrant portions being adapted to receive tuning plungers for electrically tuning said cavity resonators.

30. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving said electrons, and a cavity resonator surrounding the electron path between the cathode and collector, a tubular member extending from and supported by the inner wall of said cavity resonator, and a well within the cavity resonator supported by another portion of the inner wall of the tank circuit having its opening registering with the opening through the tubular member and a tuning plunger movable through the tubular member into the well for tuning the cavity resonator.

31. An electron discharge device having an envelope containing a cathode for supplying electrons and a collector for receiving said electrons, a control electrode adjacent the cathode for modulating said electrons and a pair of screen and accelerating electrodes positioned between the control electrode and collecting electrode and spaced apart and providing a gap therebetween, a first cavity resonator electrically coupled to said control electrode and to said cathode and providing an input circuit, a second cavity resonator electrically coupled to one of said screen and accelerating electrodes and to the cathode control electrode cavity resonator, and an output cavity resonator electrically coupled between said screen and accelerating electrodes, said cavity resonators being provided with apertures, and re-entrant tubular portions on said envelope extending within said cavity resonators through said apertures, one of said cavity resonators being provided with a tubular member extending within the cavity resonator from a wall thereof and a well supported within the cavity and having an opening registering with the opening in the tubular member and spaced from the tubular member to provide a gap, one of said re-entrant portions of the envelope extending through the tubular member into the well for receiving a tuning plunger to permit movement of the tuning plunger with respect to said gap.

32. An electron discharge device having an envelope containing a cathode for supplying electrons and a collector for receiving said electrons, a control electrode adjacent the cathode for modulating said electrons, a cavity resonator electrically coupled to said control electrode and to said cathode and providing an input circuit, said cavity resonator being provided with an aperture, a tubular member extending within the cavity resonator and supported from the inner wall of the cavity resonator, the opening in the tubular member registering with said aperture, and a well supported within the cavity resonator from the inner wall of the cavity resonator and having its opening registering with the opening in the tubular member, and a re-entrant tubular portion on the envelope extending through said aperture and tubular member into the well, said tubular member and well being spaced to provide a gap therebetween, and a tuning plunger received within the re-entrant tubular portion of the envelope and having movement longitudinally of the tubular member and well for tuning said cavity resonator tank circuit.

33. An electron discharge device having a cathode for supplying electrons and a collector for receiving said electrons, a control electrode adjacent the cathode for modulating said electrons and a screen and accelerating electrode positioned between the control electrode and collecting electrode, a first cavity resonator tank circuit electrically coupled to said control electrode and to said cathode and providing an input circuit, a second cavity resonator coupled to said screen and accelerating electrode and to said cathode-control electrode cavity resonator circuit, said second cavity resonator being provided with an aperture, a tubular member supported from the wall of said second cavity resonator, the opening in the tubular member registering with said aperture and a well supported within said second cavity resonator and having its opening registering with the opening in the tubular member, and a re-entrant tubular member forming a portion of the envelope for said electron discharge device extending through said tubular member into said well, said tubular member and well being spaced apart and providing a gap therebetween, and a tuning plunger received within the re-entrant tubular portion of the envelope and having movement longitudinally of the tubular member and well for tuning said first cavity resonator.

34. An electron discharge device having an envelope containing a cathode for supplying electrons and a collector for receiving said electrons, a control electrode adjacent the cathode, and a pair of screen and accelerating electrodes positioned between the control electrode and collecting electrode and spaced apart and providing a gap therebetween, a first cavity resonator electrically coupled to said cathode and control electrode and providing an input circuit, a second cavity resonator electrically coupled to one of said screen and accelerating electrodes and to the cathode control electrode resonant cavity tank circuit, and an output resonant cavity tank circuit electrically coupled between said screen and accelerating electrodes, said cavity resonators being provided with apertures, and re-entrant tubular portions on said envelope extending within

said cavity resonators through said apertures and a coupling loop coupling the first and second cavity resonators together extending within one of the re-entrant tubular portions, and other re-entrant portions being adapted to receive tuning plungers for electrically tuning the cavity resonators, said first cavity resonator being provided with a second aperture and a re-entrant portion extending within said second aperture and adapted to receive a coupling loop for applying a voltage to said first cavity resonator, said output resonant cavity tank circuit being provided with another aperture and a re-entrant portion of said envelope extending within said last aperture and adapted to receive a coupling loop for extracting energy from the output resonant cavity tank circuit.

35. An electron discharge device having a cathode provided with an emitting surface, a first cavity resonator coaxial with and surrounding said cathode, said first cavity resonator having an aperture registering with said emitting surface of said cathode, and a control electrode supported within said aperture adjacent to but spaced from said emitting surface of said cathode, and a second cavity resonator surrounding said first cavity resonator and spaced from said first cavity resonator and providing a gap between the cavity resonators at said control electrode, and means for collecting electrons which have passed through the grid and by said gap between the cavity resonators.

36. An electron discharge device having a cathode provided with an emitting surface, a first cavity resonator coaxial with and surrounding said cathode, said first cavity resonator having an aperture registering with said emitting surface of said cathode, and a control grid supported within said aperture adjacent to but spaced from said emitting surface of said cathode, and a second cavity resonator surrounding said first cavity resonator and spaced from said first cavity resonator and providing a gap between the cavity resonators at said grid, and means for collecting electrons which have passed through the grid and by the gap between the cavity resonators, said first cavity resonator being provided with an aperture, and a coupling loop extending through said aperture into the interior of said first cavity resonator.

37. An electron discharge device having a cathode provided with an emitting surface for providing a stream of electrons, a first cavity resonator coaxial with and surrounding said cathode, and having an aperture in one wall of said first cavity resonator registering with said emitting surface of said cathode, and a grid supported by said first cavity resonator within the aperture adjacent to but spaced from the emitting surface of said cathode, and a second cavity resonator surrounding the first cavity resonator and coaxial therewith and spaced from said first cavity resonator and providing a gap between the first and second cavity resonator adjacent said grid, and means for collecting electrons which have passed through said grid.

38. An electron discharge device including a cathode having a concave emitting surface for supplying electrons, a first cavity resonator coaxial with and surrounding said cathode and provided with an aperture in one wall registering with said concave emitting surface of said cathode, and a grid supported by said first cavity resonator within said aperture and of concave form, said cathode and grid being spaced apart and providing a gap between said emitting surface of said cathode and said grid, and a second cavity resonator surrounding but spaced from said first cavity resonator and providing a gap between said cavity resonators at said grid and means for receiving the electrons which have passed through the grid and by said gap between said cavity resonators.

39. An electron discharge device including a cathode having an emitting surface for supplying electrons, a first cavity resonator coaxial with and surrounding said cathode and provided with an aperture in one wall registering with said emitting surface of said cathode, and a control electrode supported within said aperture, said cathode and control electrode being spaced apart and providing a gap between the emitting surface of said cathode and said control electrode, and a second cavity resonator surrounding but spaced from said first cavity resonator and providing a gap between said cavity resonators at said control electrode, and means for receiving electrons which have passed through the control electrode and by the gap between said cavity resonators, said first cavity resonator having an aperture and said second cavity resonator having an aperture registering with the aperture in said first cavity resonator and coupling means extending through said apertures into the interior of said first cavity resonator.

40. An electron discharge device including a cathode having an emitting surface, a first cavity resonator coaxial with and surrounding said cathode and provided with an aperture in one wall registering with said emitting surface of said cathode, and a grid supported by said cavity resonator within the aperture, said cathode and grid being spaced apart and providing a gap between said emitting surface of said cathode and said grid, and a second cavity resonator surrounding but spaced from said first cavity resonator and providing a gap between the cavity resonators at said grid, and means for receiving electrons which have passed through said grid, said first cavity resonator having an aperture and said second cavity resonator having an aperture registering with said aperture in the first cavity resonator and a hollow tubular member extending from and surrounding each aperture, the tubular member of said first cavity resonator extending within the tubular member of said second cavity resonator and a coupling loop extending through said tubular members into the interior of said first cavity resonator.

41. An electron discharge device having a cathode electrode for supplying a stream of electrons and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector, and a screen and accelerating electrode intermediate said control electrode and collector, a first hollow member electrically coupled to said cathode electrode, a second hollow member surrounding said first hollow member and electrically coupled to said control electrode and forming with the first hollow member a first cavity resonator, a third hollow member electrically coupled to said second hollow member and said screen and accelerating electrode and providing a second cavity resonator, and means coupling said cavity resonators together.

42. An electron discharge device having a cathode electrode for supplying a stream of electrons, and a collector for collecting said electrons, a grid electrode intermediate said cathode electrode and collector, and a screen and accelerating elec-

trode intermediate said grid electrode and collector, a first hollow conducting member electrically coupled to said cathode electrode, and a second hollow conducting member electrically coupled to said grid and forming with said first hollow conducting member a cavity resonator, a third hollow conducting member electrically coupled to said screen and accelerating electrode and forming with said second hollow conducting member a second cavity resonator and coupling means coupling said cavity resonators together, and a fourth hollow conducting member positioned between the collector and said third hollow conducting member and providing a third cavity resonator for inductively extracting energy from the electron stream.

43. An electron discharge device having a cathode for supplying electrons and a collector electrode for receiving said electrons, and a cavity resonator surrounding the electron path between the cathode and collector electrode, a tubular member extending from and supported by a wall of said cavity resonator, and a well member supported by another portion of the wall of said cavity resonator and having its opening registering with the opening through the tubular member, and a tuning plunger movable through said tubular member into the well for tuning said cavity resonator.

44. An electron discharge device having a cathode electrode for supplying a stream of electrons, and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector, and a screen electrode intermediate said control electrode and collector, a hollow conducting member electrically coupled to said cathode electrode and a second hollow conducting member surrounding said first hollow conducting member and electrically coupled to said control electrode and forming with said first hollow conducting member a cavity resonator, and a conducting member electrically coupled to said second hollow conducting member and said screen electrode and providing with said second hollow conducting member a tank circuit, and means coupling the cavity resonator with said tank circuit.

45. An electron discharge device having a cathode electrode for supplying a stream of electrons, and a collector for collecting said electrons, a control electrode intermediate said cathode electrode and said collector, and a screen electrode intermediate said control electrode and collector, a hollow conducting member electrically coupled to said cathode electrode and a second hollow conducting member surrounding said first hollow conducting member and electrically coupled to said control electrode and forming with said first hollow conducting member a first cavity resonator, and a third hollow conducting member electrically coupled to said screen electrode and providing with said second hollow conducting member a second cavity resonator, and means coupling the cavity resonators together.

46. An electron discharge device having a cathode for emitting electrons and a collector for receiving electrons from the cathode, a tubular member coaxial with said cathode and capacitively coupled thereto, and a second tubular member surrounding said first tubular member and forming therewith a concentric line tank circuit, a grid supported adjacent the cathode and coupled to said second tubular member, and a hollow resonant conducting member having a gap positioned between said grid and collector and surrounding the discharge path between the grid and collector, and means coupling said concentric line tank circuit to said hollow resonant conducting member.

47. An electron discharge device having a cathode for supplying a stream of electrons, a control electrode and a collector for receiving said electrons, a lead for said cathode, a first hollow conducting member surrounding said lead and a second hollow conducting member surrounding said lead and said first hollow conducting member and capacitively coupled to said first hollow conducting member and connected to said lead, and a third hollow conducting member surrounding said first and second hollow conducting members and connected to said first hollow conducting member and coupled to said control electrode for forming a cavity resonator coupled between the cathode and control electrode, and means positioned between the control electrode and collector for extracting energy from the electron stream.

48. An electron discharge device having a cathode for supplying a stream of electrons, a control electrode, and a collector for receiving said electrons, a lead for said cathode, a tubular conducting means surrounding said lead but out of contact therewith, and a cup-shaped conducting member connected to said lead and surrounding said lead and one end of said tubular conducting member and capacitively coupled to said tubular member, and a hollow conducting member surrounding said tubular conducting members forming therewith a cavity resonator coupled between the cathode and the control electrode.

49. An electron discharge device having a cathode for supplying a stream of electrons and a collector for receiving said electrons, a lead for said cathode, a tubular conducting member surrounding said lead but out of contact therewith, a cup-shaped conducting member connected to said lead and capacitively coupled to one end of said tubular conducting member, and a hollow conducting member surrounding said tubular conducting member and forming therewith a cavity resonator coupled to said cathode and surrounding the electron path between said cathode and said collector.

50. An electron discharge device having a cathode for supplying a stream of electrons and a collector for receiving said electrons, a lead for said cathode, a cavity resonator surrounding the electron discharge path between the cathode and the collector and provided with a reentrant tubular portion surrounding said lead, and a cup-shaped conducting member connected to said lead and surrounding said lead and capacitively coupled to the end of the re-entrant tubular portion on said cavity resonator.

ANDREW V. HAEFF.

Certificate of Correction

Patent No. 2,399,223. **April 30, 1946.**

ANDREW V. HAEFF

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 10, second column, line 29, claim 32 and line 36, claim 33, strike out "tank circuit"; line 41, strike out "circuit"; lines 70 and 71, 71 and 72, and page 11, first column, line 12 and lines 16 and 17, claim 34, for "resonant cavity tank circuit" read *cavity resonator*; same page 11, second column, line 6, claim 38, for "the grid and by said" read *said grid and by the*; line 46, claim 40, for "said aperture in the" read *the aperture in said*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 5th day of November, A. D. 1946.

[SEAL]

LESLIE FRAZER,
First Assistant Commissioner of Patents.

Disclaimer

2,399,223.—*Andrew V. Haeff, East Orange, N. J.* ELECTRON DISCHARGE DEVICE. Patent dated Apr. 30, 1946. Disclaimer filed Mar. 9, 1948, by the assignee, *Radio Corporation of America.*

Hereby disclaims claims 1, 5, 12, 41, 44, and 45 of said patent.

(Official Gazette April 6, 1948.)