Oct. 31, 1950 A. V. HAEFF 2,528,138

HIGH-FREQUENCY ELECTRON DISCHARGE DEVICE

Original Filed Jan. 18, 1941 2 Sheets-Sheet 1

Fig. 1.

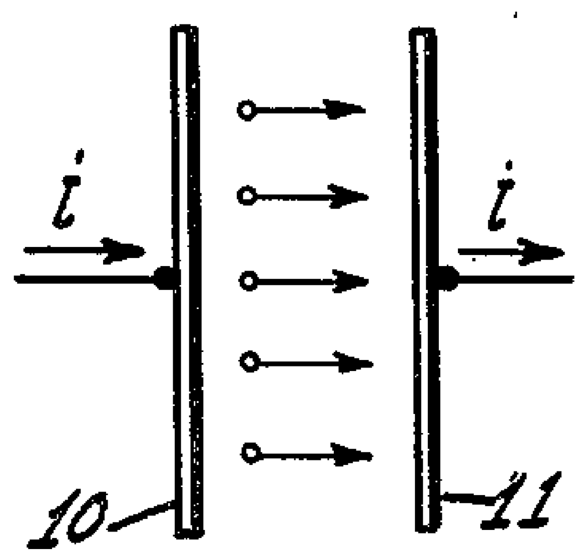


Fig. 2.

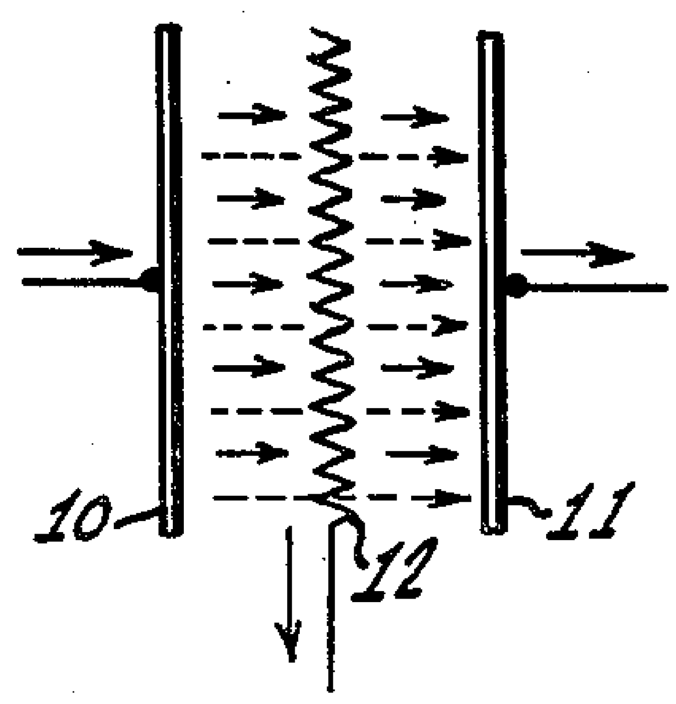


Fig. 5.

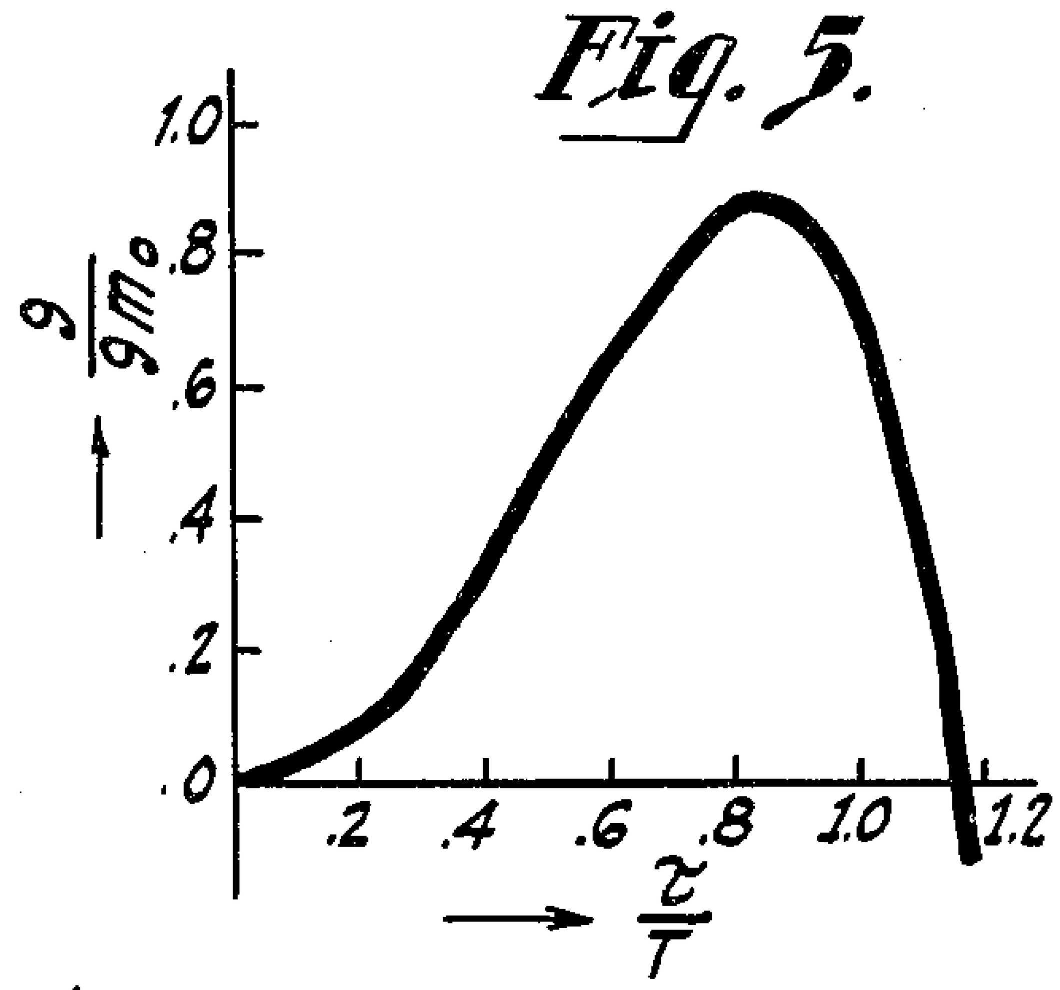


Fig. 6.

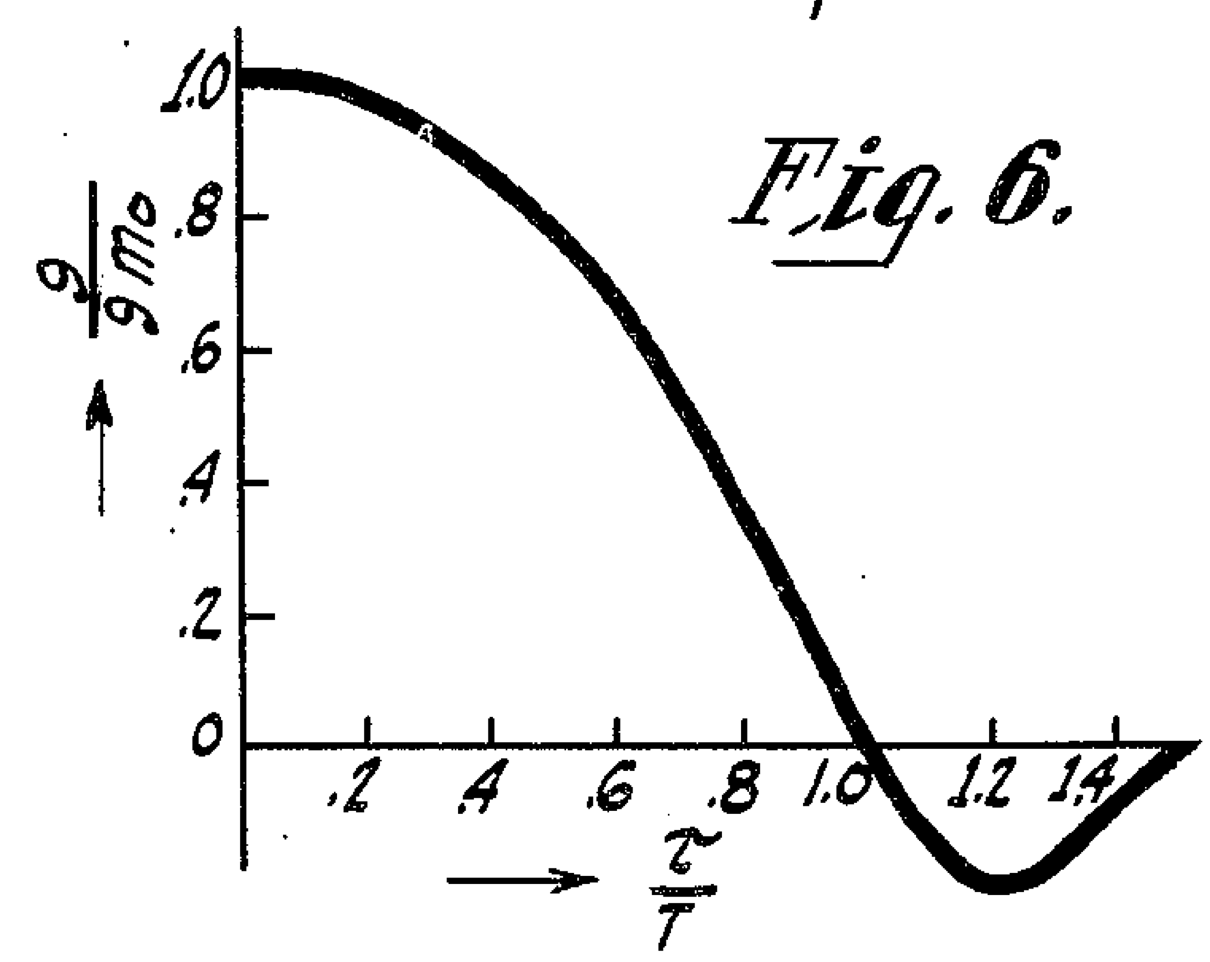


Fig. 3.

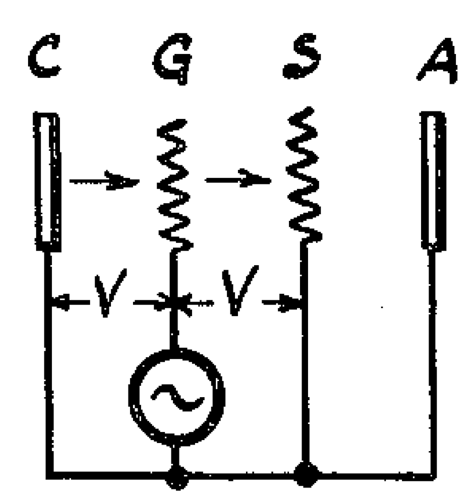


Fig. 4.

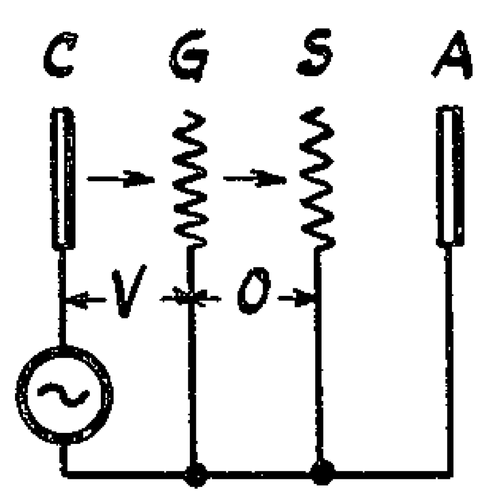


Fig. 9.

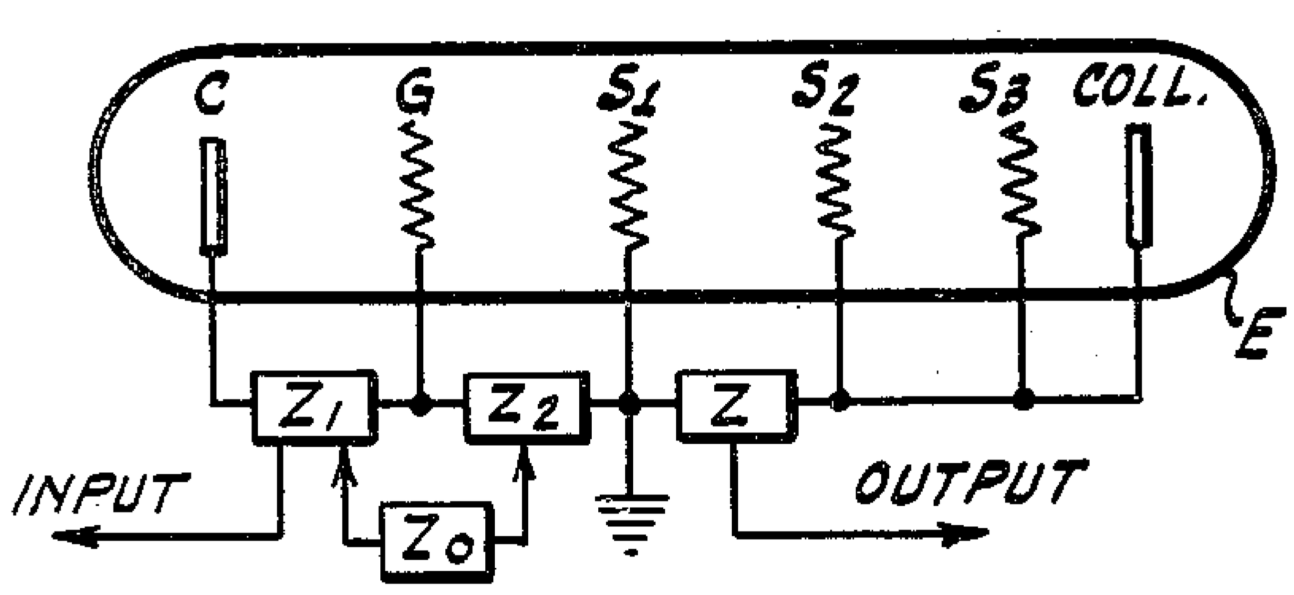


Fig. 7.

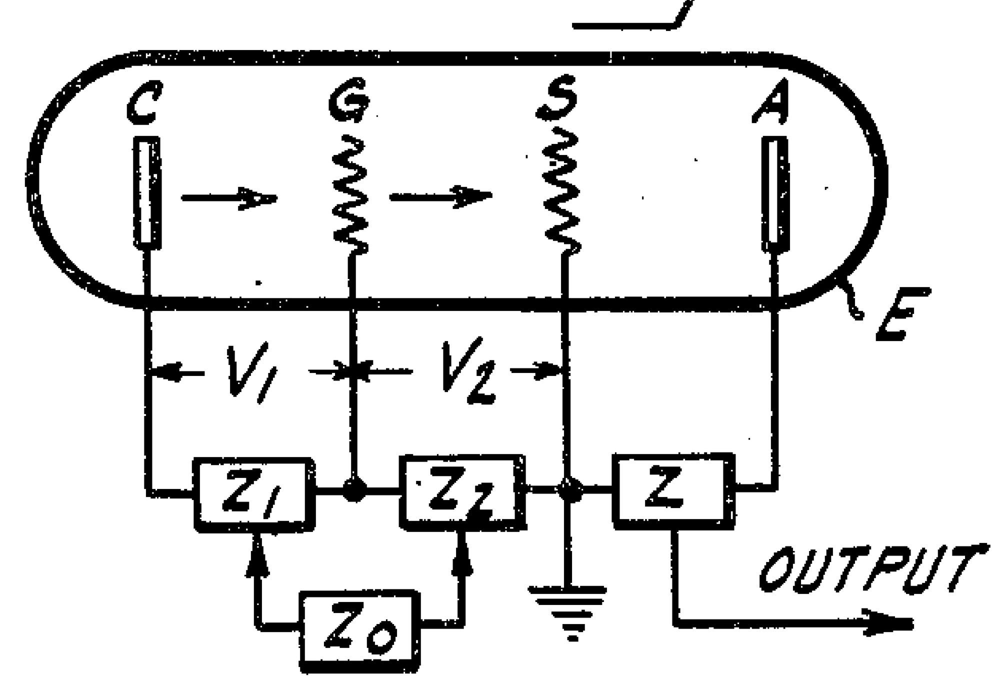


Fig. 8.

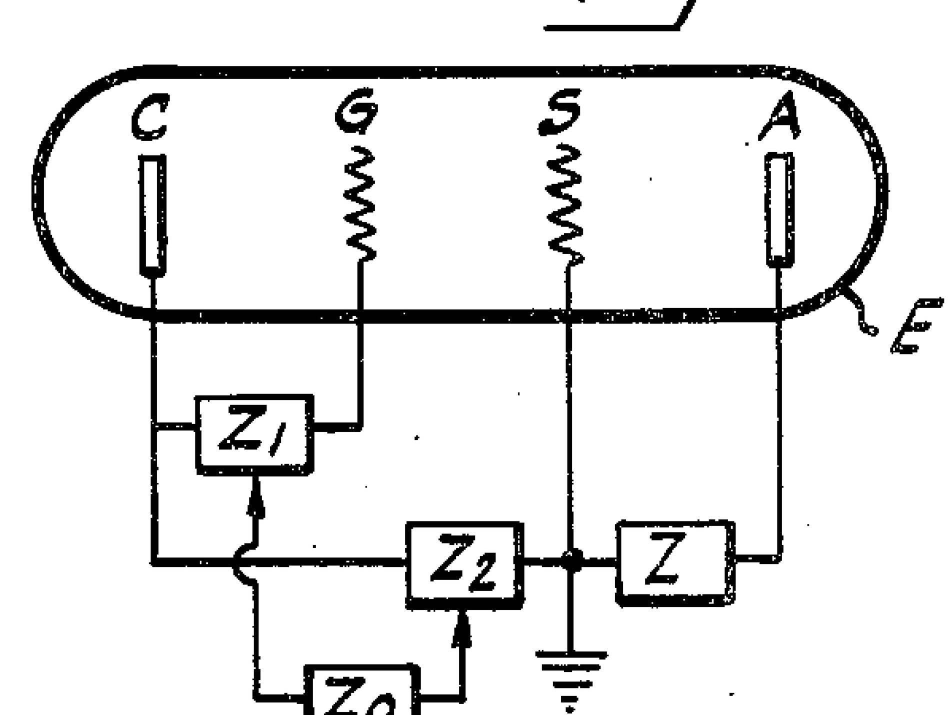
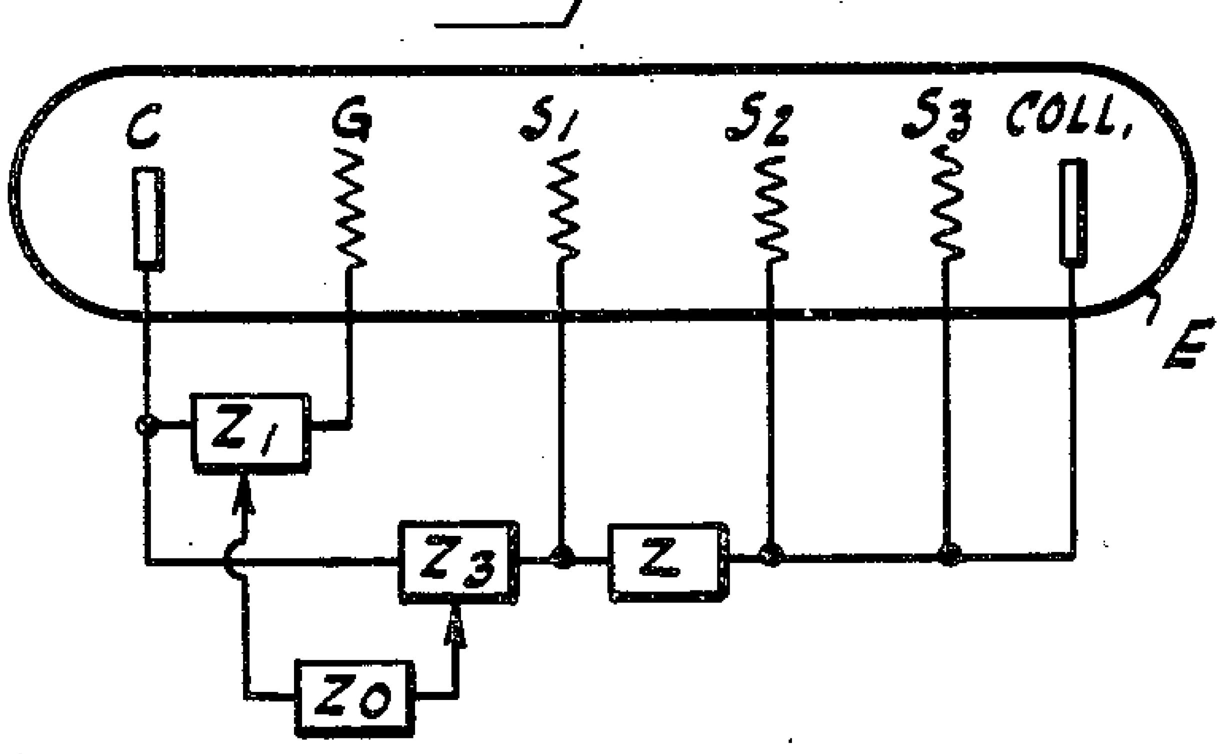


Fig. 10.



INVENTOR
ANDREW V. HAEFF.
BY Charles McClair
ATTORNEY

Oct. 31, 1950 A. V. HAEFF 2,528,138

HIGH-FREQUENCY ELECTRON DISCHARGE DEVICE

Original Filed Jan. 18, 1941 2 Sheets-Sheet 2

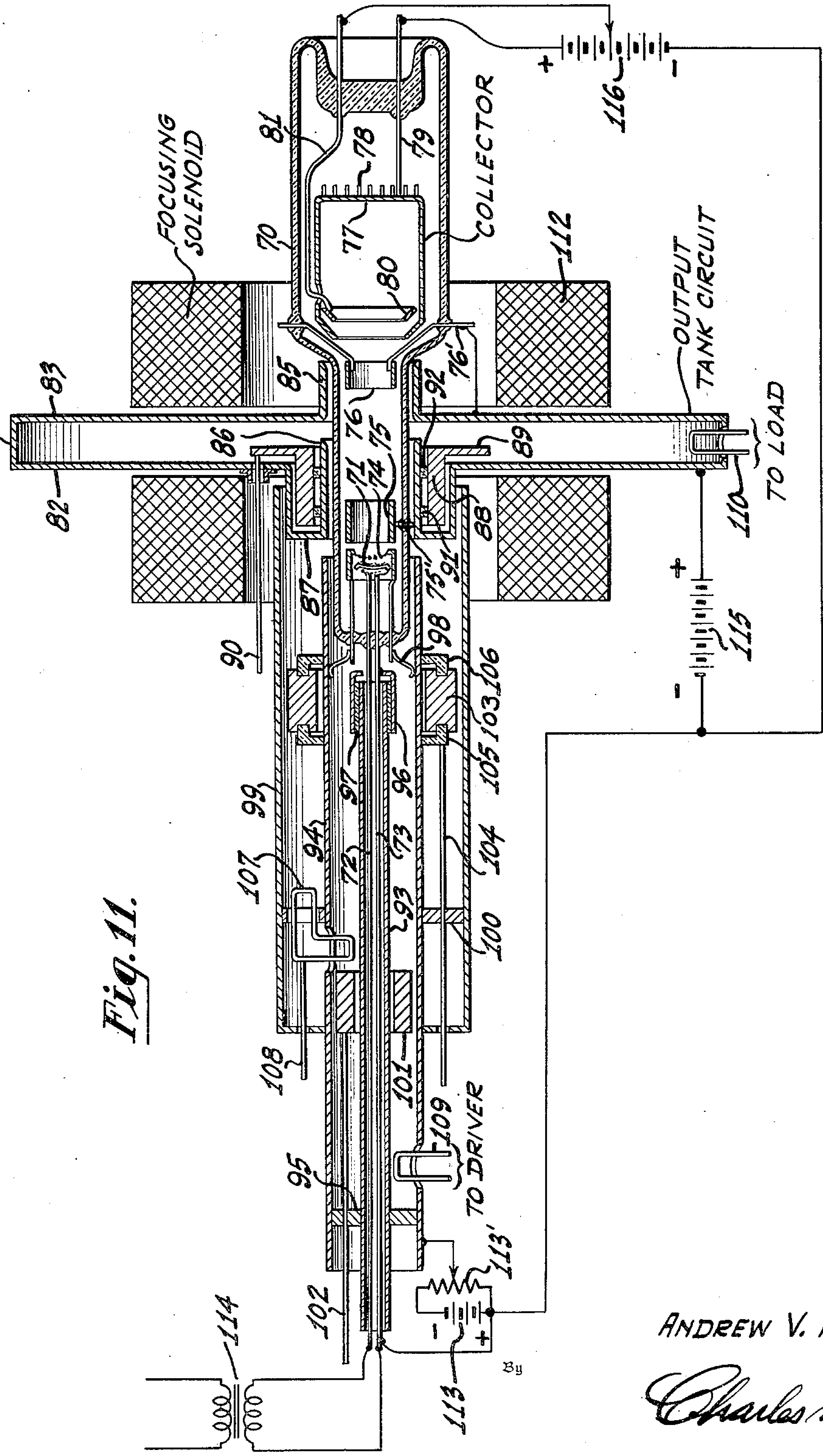


Fig. 11.

Inventor

ANDREW V. HAEFF

By

Charles McClair

Attorney

Patented Oct. 31, 1950

2,528,138

UNITED STATES PATENT OFFICE

2,528,138

HIGH-FREQUENCY ELECTRON DISCHARGE DEVICE

Andrew V. Haeff, Washington, D. C., assignor to Radio Corporation of America, a corporation of Delaware

Original application January 18, 1941, Serial No. 375,029. Divided and this application August 14, 1945, Serial No. 610,700

4 Claims. (Cl. 315—6)

1

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

The present application is a division of my copending application, Serial No. 375,029, filed January 18, 1941 now Patent No. 2,399,223, issued April 30, 1946, and assigned to the same assignee as the present application.

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 5; Figures 7 to 10 inclusive are diagrammatic representations of tubes and circuits made according to my invention for practicing my invention; and Figure 11 is a longitudinal section of an electron discharge device made according to my invention.

2

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 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 $W_{10-12}+W_{12-10}+W_{10-11}$ 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/Gm_0 where G=conductance of the grid G due to electron motions and G_{m0}= 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 Fig. 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 comparison, 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 supplemented 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 showns 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 an inductive output 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.

In Figure 11 is shown a longitudinal section of an electron discharge device and associated circuit made according to my invention in which all of the resonant cavity circuits or cavity resonators 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 electrodes 75 and 76 being supported from the glass envelope by means of leads 75′ and 76′. The collector 77 is provided with the heat 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 inductive output or 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 hollow 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 leads 75′ and 76′ are connected to the extension 87 and the disc 83, respectively.

The cathode-grid concentric line circuit or input cavity resonator comprises the inner tubular member 93 which serves to shield the heater leads, the outer tubular member 94 coaxial with and concentric with the inner tubular member 93, and the apertured shorting disc 95 electrically connecting the two tubular members. The cathode 71 is capacitively coupled to the inner tubular member 93 by means of the cup-shaped extension 96 electrically connected to the cathode lead 73 and insulatingly supported on the inner tubular member by means of the insulating collar 97. The grid 74 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 apertured disc-shaped member 100. The

open end of tubular member 99 is capacitively coupled to the extension 87 of disc 82. The cathode-control grid circuit is tuned by means of a hollow cylinder 101 slidably mounted between tubular members 93 and 94 and provided with an adjusting rod 102. The screen electrode-control grid circuit is tuned by means of the hollow 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 apertures in members 100 and 94, 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, selenoids 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.

In operation electrons from the cathode 71 are formed into a directed beam and controlled by the cup-shaped grid 74. These electrons pass through the acclerating electrodes 75 and 76 to the collector 77. The electrons are modulated by the grid between which and the cathode 71 is coupled the coaxial line input resonator comprising the inner conductor 93 and outer conductor 94 electrically closed by the closure member 95. Electrons passing across the gap between the grid 74 and accelerating electrode 75 energize the cavity resonator coupled between the grid and accelerating electrode and comprising the tubular members 94 and 99, feedback to the cathode-control grid circuit being accomplished by the coupling loop 107 to cause the device to act as an oscillator. This modulated stream of electrons passing across the gap of the output tank circuit resonator excites the resonator, energy being coupled out of the resonator to a load by means of the coupling loop 110.

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.

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 for emitting electrons and a collector for receiving said electrons, a tubular member coupled to said cathode, a second tubular member surrounding said first tubular member and forming therewith a concentric line cavity resonator, a grid supported adjacent the cathode and coupled to said second tubular member, and a second cavity resonator surrounding the path of the electrons from the cathode to said collector and having a gap positioned between said grid and collector, said last cavity resonator comprising a pair of planar conductors having registering outer peripheries and positioned in face-to-face relationship, said tubular members extending at right angles to said planar members.

2. An electron discharge device having a cathode for supplying electrons, a grid and a collector, in the order named a cavity resonator surrounding the path of the electrons between said grid and said collector and including a pair of disc-like members spaced apart and joined together at their peripheries by a conducting member, the interior of said resonator communicating with the space between the grid and the collector, a first tubular member coupled to said cathode, and a second tubular member coaxial with said first tubular member and coupled to said grid, said tubular members providing an input cavity resonator extending normally to the walls of the first cavity resonator.

3. An electron discharge device having a cathode, a grid and a collector in the order named, an

input cavity resonator including a first tubular member coupled to said cathode and a second tubular member coaxial with said first tubular member and coupled to said grid, and an output resonator positioned between said grid and said collector and including a flattened drum-shaped structure comprising a pair of oppositely disposed disc-like conducting members joined at their peripheries by a conducting ring, the surfaces of said disc-like members lying in a plane normal to the longitudinal axis of the tubular members.

4. An electron discharge device having a cathode, grid, an accelerator and a collector in the order named, a first tubular member coupled to said cathode, a second tubular member coaxial with said first tubular member and coupled to said grid, said tubular members providing an input circuit, a third tubular member surrounding said second tubular member and coupled to said accelerator and providing therewith a grid-accelerator cavity resonator, and a flattened drum-like cavity resonator positioned between said accelerator and said collector and including a pair of spaced disc-like conducting members extending transversely of the longitudinal axis of the tubular members and a conducting ring-like member joining the periphery of said disc-like members.

ANDREW V. HAEFF.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,225,447	Haeff et al.	Dec. 17, 1940
2,227,372	Webster et al.	Dec. 31, 1940
2,278,210	Morton	Mar. 31, 1942
2,293,152	Litton	Aug. 18, 1942
2,353,742	McArthur	July 18, 1944
2,400,752	Haeff	May 21, 1946