

April 23, 1946.

A. V. HAEFF

2,398,829

ELECTRON DISCHARGE DEVICE

Filed May 28, 1941

3 Sheets-Sheet 1

Fig. 1

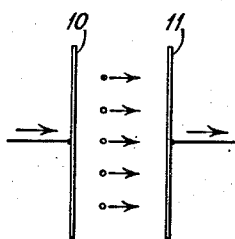


Fig. 2

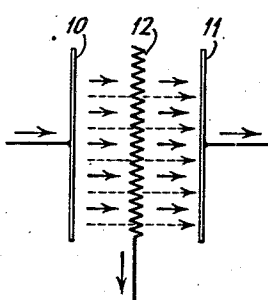


Fig. 5

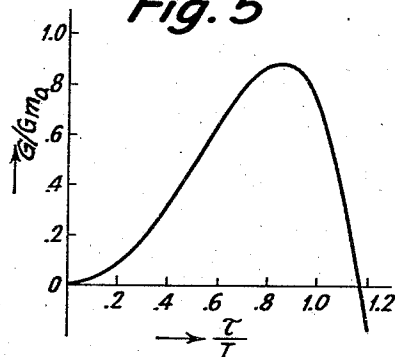


Fig. 3

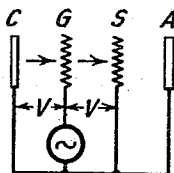


Fig. 4

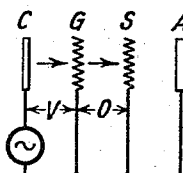


Fig. 6

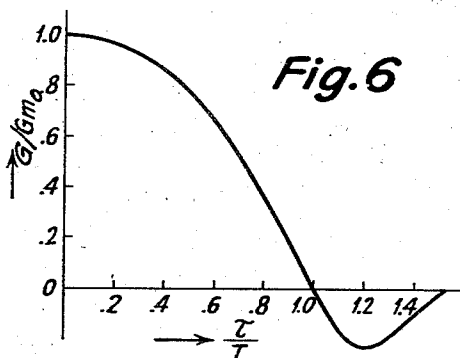


Fig. 8

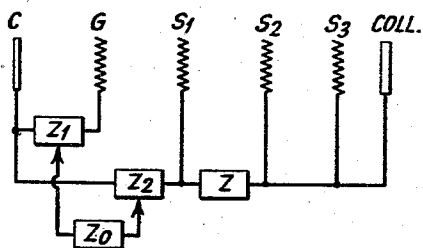
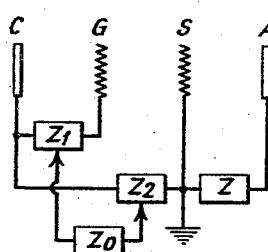


Fig. 7



INVENTOR.
ANDREW V. HAEFF
BY *Charles McClair*
ATTORNEY.

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A. V. HAEFF

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3 Sheets-Sheet 2

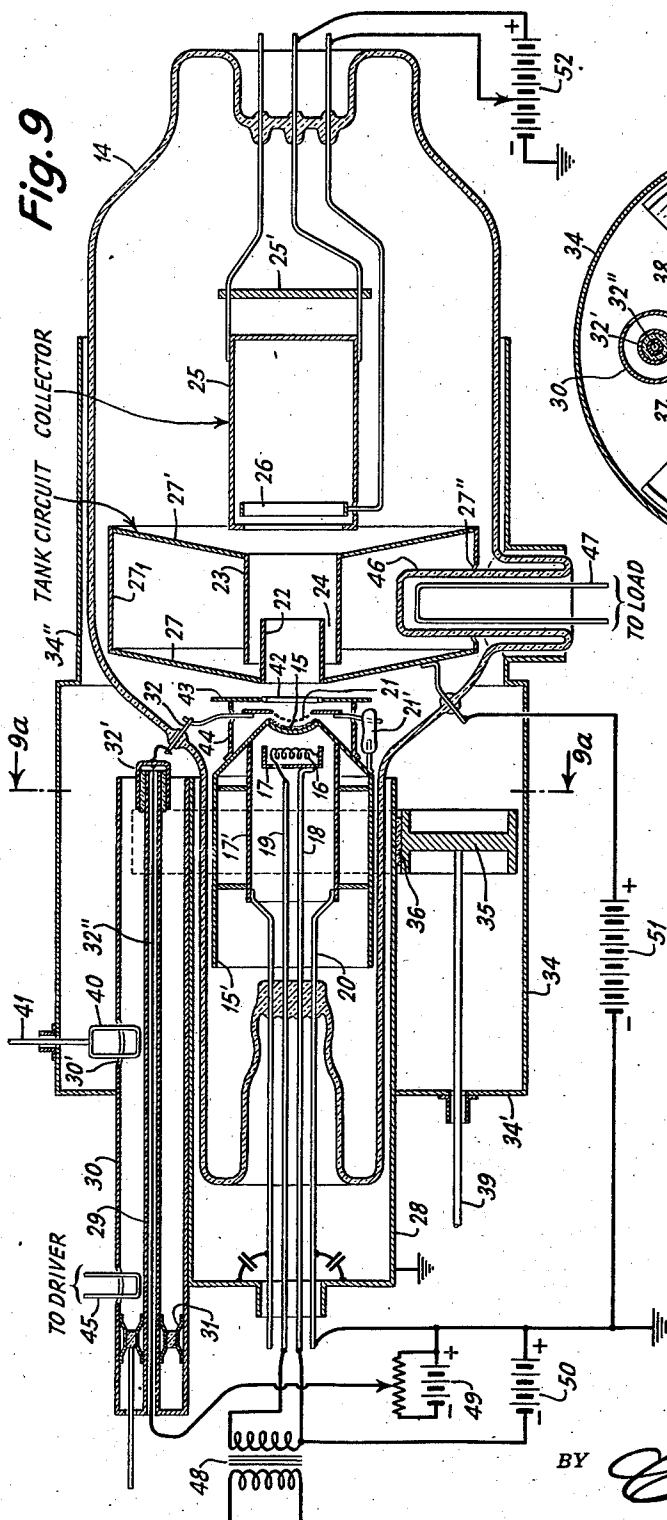
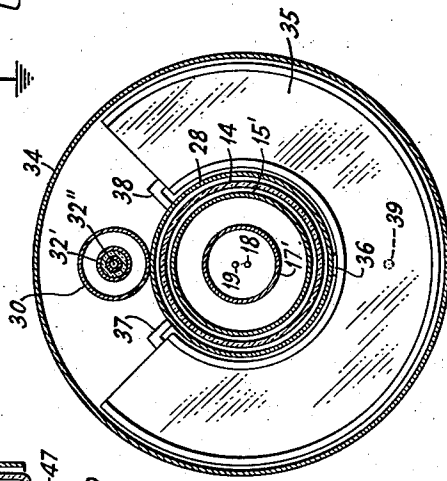


Fig. 9a

INVENTOR.
ANDREW V. HAEFF
BY *Charles McClair*
ATTORNEY.

April 23, 1946.

A. V. HAEFF

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3 Sheets-Sheet 3

Fig. 10

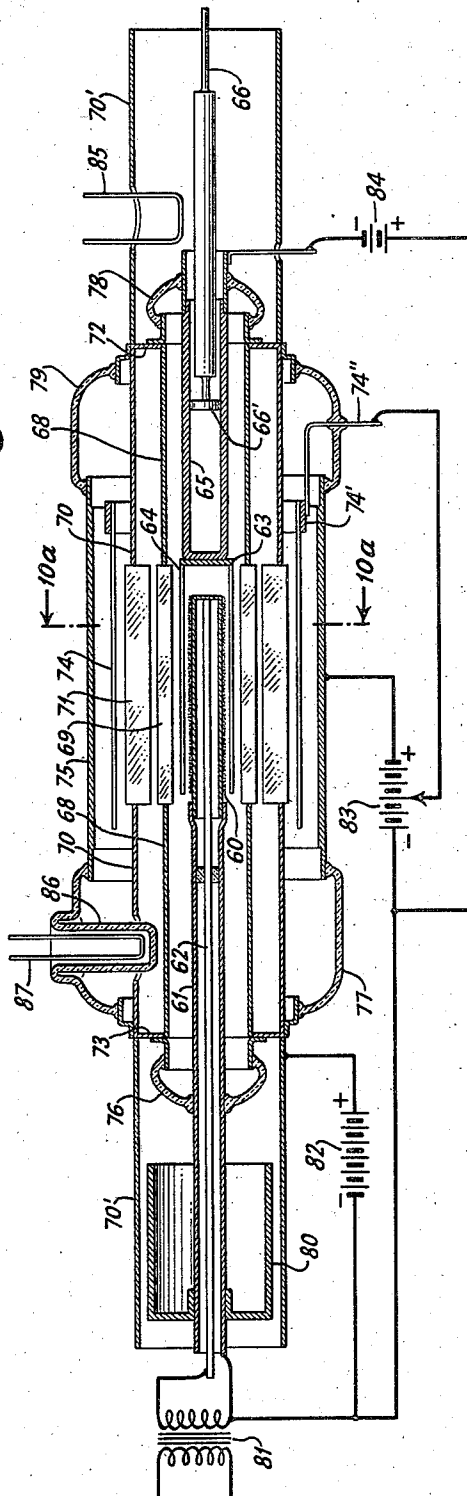
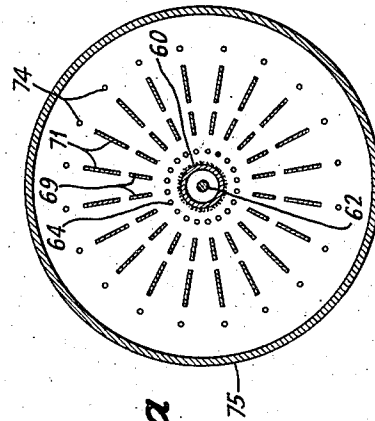


Fig. 10a

INVENTOR.
ANDREW V. HAEFF
BY *Charles McClair*
ATTORNEY.

UNITED STATES PATENT OFFICE

2,398,829

ELECTRON DISCHARGE DEVICE

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

Application May 28, 1941, Serial No. 395,609

25 Claims. (Cl. 315-5)

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 continuation in part of my co-
5 pending application, Serial No. 375,029, filed January 18, 1941 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 drawings 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
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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 and 8 are diagrammatic representations of tubes and circuits made according to my invention for practicing my invention; Figure 9 is a longitudinal section of an electron discharge device made according to my invention; Figure 9a is a section taken along the line 9a-9a of Figure 9; Figure 10 is a longitudinal section of a modification of an electron discharge device made according to my invention; and Figure 10a is a section taken along the line 10a-10a of Figure 10.

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:

$$W_{10-12} = i_{10-12} V_{10-12} \cos \phi_{10-12}$$

$$W_{12-11} = i_{12-11} V_{12-11} \cos \phi_{12-11}$$

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

$$W_{10-11} = i_{10-11} V_{10-11} \cos \phi_{10-11}$$

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

$$W = W_{1-2} + W_{2-3} + W_{3-1} + \dots$$

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 ($W = i_{V_{C-G}} - i_{V_{G-S}} \approx 0$). 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 relative to the 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/G_m where G =conductance of the grid G due to electron motions and G_m =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 the 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 $W_2 = i_{G-S} V_2 \cos(\phi_{G-S} - \phi_{V_2})$ 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 schematic diagram of such a circuit is shown in Figure 7. An impedance Z_2 is introduced between the screen S and the cathode C of such magnitude and phase angle that the current i_{G-S} will produce a voltage V_2 across the impedance. The power $W_2 = i_{G-S} V_2 \cos(\phi_{G-S} - \phi_{V_2})$ generated in the G—S space is then fed to the grid-cathode circuit Z_1 by means of coupling circuit Z_0 . The impedances Z_1 and Z_2 usual take the form of tuned circuits, and the coupling impedance Z_0 may be the inter-electrode capacitance or an auxiliary coupling element. The coupling between the circuits Z_1 and Z_2 may also be provided by the control grid to screen capacitance or it can be supplemented by the auxiliary coupling circuit Z_0 . In Figure 7 a conventional output circuit with an output impedance (Z) connected between the anode and the screen is shown. However, other types of output circuits can be used, since the input loading neutralization scheme here proposed is no way depends upon the extraction of energy from the output circuit.

Figure 8 represents schematically the input circuit arrangement of Figure 7 in combination with an 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 in-

incorporated in a so-called "inductive output tube" is shown in detail in Figure 9. "Inductive output tubes" and their operation are described more fully in Patent 2,237,878 to A. V. Haeff based on application, Serial No. 254,239, filed February 2, 1939, and assigned to the same assignee as the present application. 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 pass to the collector. Surrounding the beam path is a resonant cavity circuit comprising a hollow member having a passageway extending there-through 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 9, the tube is provided with an exhausted envelope 14 containing 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 helix and surrounded by a focusing shield or cup 17 for directing the electrons from the filament to the cathode 15. The cathode helix 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 supported from tubular member 15' by insulating glass beads 21', and passes through a pair of concentric tubular screen and accelerating 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 suppressor ring 26 for preventing any secondary electrons from leaving the collector. The output circuit is of the closed resonant cavity type and is formed by the two electrodes 22 and 23 and metal surfaces 27 and 27' jointed at the periphery by a short cylindrical section 271.

In order to practice my invention the cathode supporting cylinder 15' is mounted close to the glass wall of envelope 14 so that high capacitance between it and externally placed tubular member 28 of cylindrical form, will serve to by-pass the radio frequency current from the cathode to the cylinder 28. Thus the leads for the heater and cathode are shielded by means of the tubular member 28. The cathode grid circuit is formed by the tubular members 29 and 30 which constitute the inner and outer conductors of a concentric line tuned by the longitudinally movable plunger 31. This cathode-grid circuit corresponds to impedance Z_1 of Figure 8. As pointed out above, the large capacitance between the cathode support or extension 15' and cylindrical member 28 serves to by-pass radio frequency current from the cathode to the tubular member 28. The grid lead 32 extending through the envelope 14 of the tube is capacity coupled to the end of the inner hollow conductor 29 by means of the cup-shaped coupling condenser 32'. This permits the application of a direct voltage bias on the grid different from that on the tubular member 29, by means of the lead 32''.

The screen and accelerating electrode-control electrode circuit will now be described. Sur-

rounding the cathode cylinder 28 is a tubular member 34 closed at one end by means of a ring-shaped member 34'. The member 34 is provided with tubular extension 34'' surrounding the collector end of the envelope 14 and capacitively coupled to the resonant cavity tank circuit which is electrically connected to the screening and accelerating electrodes 22 and 23. These members 34, 34', 34'' form with the cathode cylinder 28 and the disc 27 a resonant cavity tank circuit electrically coupled to the screen and accelerating electrode 22 and the cathode. It will be observed that the grid-cathode circuit is shielded from the cathode-screen circuit by means of the outer tubular member 30, the cathode-grid circuit and the screen grid-cathode circuit being electrically coupled by means of coupling loop 40 supported and adjusted by means of extension 41 within the aperture 30' in member 30. The screen grid-cathode tank circuit may be tuned by means of a sliding condenser 35, made in the form of an open ring and resting on insulators 36, 37 and 38, which slide along the cylinder 28 when adjusted by means of the rod 39. While coupling between the grid-cathode and screen-cathode circuits is also provided by the screen-to-grid capacitance, the metal coupling loop 40, coupling the magnetic fields of the two circuits can be used to control the amount of the coupling. The input is coupled to the grid-cathode circuit by means of the driver coupling loop 45 and the load is coupled to the output resonant cavity circuit or cavity resonator by means of the coupling loop 47 extending within the re-entrant portion 46 of the envelope, which extends within an aperture 27' in the tank circuit.

To prevent electrons from impinging on the high potential electrodes 22 and 23, a focusing ring 42 is placed between the control grid 21 and screen and accelerating electrode 22. The focusing ring is supported on the cathode by means of cylinder 44, and together with flat ring 43 serves to prevent deposition on the glass wall of the tube of the material evaporated from the cathode. To distribute heat generated within the cathode space, heat shields 17' are placed within the cathode cylinder 15'. A heat shield 25' may be placed behind the collector to prevent overheating the glass stem supporting the collector.

The heating potential for the cathode filament 16 is provided by means of the cathode filament transformer 48 and the bias for the cathode 15 to cause bombardment of the same by electrons emitted by the cathode filament 16 is supplied by voltage source 50. Grid 21 is biased negatively with respect to the cathode 15 by means of voltage source 49 electrically connected to control grid 21 by lead 32'' within tubular member 29. The tank circuit and screen and accelerating electrodes are maintained at high positive potentials with respect to the cathode and grid by means of voltage source 51 and the collector is maintained at a lower positive potential than the tank circuit by means of potential source 52, the suppressor ring or electrode 26 being at a lower positive potential than the collector electrode 25.

In operation the input voltage is applied to the cathode-grid concentric line input tank circuit by means of the loop 45. The electrons emitted by cathode 15 are modulated by grid 21 and pass through the first accelerating and screen electrode 22, the second accelerating electrode 23 connected to the resonant cavity tank circuit 27,

27, 27' to the collector 25. In passing through the tank circuit the modulated stream of electrons passes by the gap 24 formed between the two accelerating and screen electrodes to inductively energize the tank circuit, the load being taken from the tank circuit by means of coupling loop 47. The modulated beam of electrons in passing between control grid 21 and screen electrode 22 induces a voltage in the screen electrode-cathode tank circuit described above. Some of this energy is fed back into the grid-cathode circuit because of the capacity between grid 21 and screen electrode 22. However, the amount of feed back is largely determined by the coupling loop 40 which couples resonant cavity screen electrode-cathode circuit and the control grid-cathode circuit.

It will thus be apparent that by means of the construction shown in Figures 9 and 9a 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 Figures 10 and 10a are shown modifications of the device shown in Figure 9. This arrangement employs a concentric electrode arrangement in which the various electrodes are connected at their ends to tubular members which cooperate to form resonant cavity or concentric line tank circuits.

The cathode 60 coated with emitting material is supported by and electrically connected to tubular member 61 on the inside of which is conductor 62, the two members serving as the leads for the heating current for the cathode sleeve, the resistance of the cathode sleeve being depended upon to provide heating by the passage of the current of the cathode to cause emission. Supported from the other end of the tube is the control grid comprising a disc member 63 supporting a plurality of longitudinally extending fingers or rods 64 parallel to and surrounding the cathode. The grid is supported by means of hollow tubular conductor 65 properly sealed into the envelope of the tube, the rod 66 having on the end thereof a disc-like member 66' electrically contacting the interior tubular member 65. The rod 66 is movable longitudinally of member 65 for varying its effective length for tuning purposes. The first screen electrode 69 comprising a plurality of radially positioned slat-like elements is connected at each end to a tubular member 68. The next screen and accelerating electrode 71 comprises a plurality of regularly positioned slat-like members also connected at each end to a tubular member 70. The tubular members 68 and 70 are electrically connected together at their ends by means of disc-like elements 72 and 73. Thus a resonant cavity tank circuit is formed comprising the slat-like accelerating and screen electrodes 69 and 71, tubular members 68 and 70, and end members 72 and 73.

Positioned in radial alignment with the slat-like members are the rods 74 surrounding the

accelerating electrodes and mounted in ring 74' provided with a lead 74'' through which the proper bias may be applied to the suppressor grid. The collector electrode 75 is positioned outside of and surrounding all of the other electrodes. A sealed envelope for the electrodes, which envelope can be evacuated, is formed by providing the cup-shaped sealing members 76 and 78 connected between the tubular members 68 and the cathode tubular member 61 and grid tubular member 65 respectively, the collector being sealed to the resonant cavity by means of the insulating cup-shaped sealing members 77 and 79.

As shown, the outer tubular members 70 are provided with hollow extensions 70', a sliding cup-shaped condenser 80 forming a closure and short circuiting element for tuning the screen grid-cathode electrode circuit formed at one end. The screen grid-control grid circuit at the other end is formed between the grid support and extension 65—66 and members 68 and 70. Movement of 66 varies the effective length of the grid conductor 65 and hence tuning of the grid-screen circuit.

Heating potential is supplied by heating transformer 81 and the potential for the screen and accelerating electrode by voltage source 82, the suppressor grid voltage being supplied by means of voltage source 83, which also supplies the positive collector voltage which is at a lower potential than the screen voltage. Proper grid bias is supplied by means of potential source 84.

In operation electrons emitted by the cathode 60 pass through and are modulated and formed into beams by means of grid 64, after which they pass through slat-like screen electrodes 69 and 71 to induce a voltage in the tank circuit connected to these electrodes, after which they are collected by collector 75. The grid circuit is coupled to the cathode circuit by means of the grid-cathode capacitance. The input is coupled to the grid by means of coupling loop 85. The load is coupled to the tank circuit by means of coupling loop 87.

The electron discharge device shown in Figures 10 and 10a illustrates an extreme case of the arrangement shown in the diagram of Figure 8. The cathode-to-screen circuit of the present tube corresponds to the impedance Z_2 in Figure 8 and the cathode-to-control grid capacitance is equivalent to the impedance Z_1 , the grid-to-screen circuit being equivalent to impedance Z_0 .

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 the cathode electrode and screen electrode, said impedances being electrically shielded from each other and means electrically coupling said impedances together.

2. 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 the cathode electrode and screen electrode, and means electrically coupling said impedances together, and means intermediate said screen electrode and said collector for inductively extracting energy from the electron stream as it moves from said cathode to said collector.

3. 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 for modulating said stream 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 cathode electrode and screen electrode, means electrically coupling said impedances together, and a cavity resonator surrounding the path of said stream between the control electrode and the collector for inductively abstracting energy from said stream.

4. 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 tubular member electrically coupled to said screen electrode and surrounding said first tubular member and forming with said first tubular member a cavity resonator, a conducting member electrically coupled to said control electrode and a tubular member surrounding said conducting member and electrically coupled with said cathode electrode, and means coupling said cavity resonator and said control electrode.

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 second tubular member coaxial and within said first tubular member and electrically coupled to said control electrode and

forming with the first tubular member a first cavity resonator, a third tubular member surrounding said first and second tubular members and electrically coupled to said screen electrode and providing a second cavity resonator, and means coupling said cavity resonators 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 first conducting member electrically coupled to said cathode electrode, a second conducting member electrically coupled to said control electrode, said first conducting member surrounding said second conducting member and forming therewith a cavity resonator, a third conducting member electrically coupled to said screen electrode and surrounding said first and second conducting members and providing a second cavity resonator, and coupling means coupling said cavity resonators together, and other circuit means having a gap surrounding the electron stream between the cathode electrode and collector for inductively extracting energy from said electron stream.

7. 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 coupled to said control electrode and within said first tubular member and forming therewith a concentric line circuit, an impedance electrically connected between said screen electrode and said first tubular member, and coupling means electrically coupling said concentric line circuit with said impedance.

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 one end of said screen electrode and surrounding said first tubular member and forming therewith a cavity resonator, a third tubular member electrically connected to the other end of said screen electrode, a fourth tubular member within said third tubular member and electrically coupled to said control electrode and forming with the third tubular member a concentric line circuit.

9. 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 electrode and a screen electrode intermediate said control electrode and collector electrode, a cavity resonator coupled between the cathode electrode and screen electrode, a second cavity resonator coupled between said control electrode and said cathode 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

and positioned between the screen electrode and the collector electrode.

10. 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 screen electrode and forming with said first tubular member a cavity resonator, and a third tubular member electrically coupled to said control electrode and surrounded by a tubular member electrically coupled to said first tubular member coupled to said cathode electrode and providing with said third tubular member a cavity resonator, and means coupling said cavity resonators together.

11. 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 member and electrically coupled to said screen electrode and forming with said first tubular member a cavity resonator, and a third tubular member coupled to said control electrode, a tubular member surrounding and coaxial with the third tubular member and providing therewith a cavity resonator, and means coupling said cavity resonators together, and a cavity resonator having a passageway therethrough and positioned between the screen electrode and the collector and surrounding the discharge path between the control electrode and the collector for inductively extracting energy from the stream of electrons.

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 said cathode electrode and collector and a screen electrode intermediate said control electrode and collector, an elongated conducting member coupled to said cathode electrode, a conducting member electrically coupled to said screen electrode and surrounding said elongated conducting member and forming with said elongated conducting member a cavity resonator, a first conducting member electrically coupled to said control electrode and a second conducting member electrically coupled with said elongated conducting member, said first and second conducting members forming a cavity resonator, and means coupling said cavity resonators together.

13. An electron discharge device having a cathode including an elongated cup-shaped member provided at the closed end with an emitting surface for providing a stream of electrons, a collector electrode for receiving said electrons from said cathode, a hollow conducting member surrounding said cup-shaped member and capacitively coupled thereto, a control electrode positioned adjacent the emitting surface of said cathode and between said cathode and collector electrode, and a screen and accelerating electrode positioned between said control electrode and said collector electrode, a cavity resonator circuit

surrounding the electron discharge path between the screen electrode and collector electrode and electrically coupled to said screen electrode, a second hollow conducting member surrounding the first hollow conducting member and forming therewith a cavity resonator, and having an extension capacitively coupled with said cavity resonator circuit to provide a screen electrode-cathode cavity resonator, a conducting member extending within the screen electrode-cathode cavity resonator and coupled to said control electrode, and a hollow conducting member surrounding the conducting member coupled to said control electrode, the control electrode conducting member and the member surrounding said control electrode conducting member forming an input cavity resonator for said control electrode, and a coupling loop coupling the control electrode cavity resonator and the screen electrode-cathode cavity resonator.

14. An electron discharge device having a cathode including an elongated cup-shaped member provided at the closed end with an emitting surface for providing a stream of electrons, a collector electrode for receiving electrons from said cathode, a first hollow conducting member surrounding said cup-shaped member and capacitively coupled thereto, a control electrode positioned adjacent the emitting surface of said cathode and between said cathode and collector electrode, and a screen and accelerating electrode positioned between said control electrode and said collector electrode, a first cavity resonator surrounding the electron discharge path between the screen electrode and collector electrode and electrically coupled to said screen electrode, a second hollow conducting member surrounding the first hollow conducting member and forming therewith a second cavity resonator, and having an extension capacitively coupled with said first cavity resonator to provide a screen electrode-cathode cavity resonator, a conducting member extending within the screen electrode-cathode cavity resonator and coupled to said control electrode, and a hollow conducting member surrounding the control electrode conducting member, said control electrode conducting member and the member surrounding said control electrode conducting member forming an input cavity resonator for said control electrode, and a coupling loop coupling the control electrode cavity resonator and the screen electrode-cathode cavity resonator, and a tuning condenser within said screen electrode-cathode cavity resonator movable longitudinally of said cavity resonator for tuning the same.

15. An electron discharge device comprising an elongated cup-shaped cathode having an emitting surface at one end, a control grid supported next adjacent said emitting surface, a screen and accelerating electrode and a collector, all in the order named, a cavity resonator positioned between the accelerating electrode and the collector and surrounding the discharge path between the cathode and the collector, a tubular member closely surrounding the cup-shaped cathode and capacitively coupled thereto and extending away from the emitting surface of said cathode, a second tubular member surrounding said first tubular member and provided with an extension surrounding said cavity resonator, said tubular members forming a second cavity resonator between said cathode and said screening electrode, concentric tubular members extending within the space of the screen electrode-cathode cavity res-

onator and coupled between the inner of the two tubular members and the grid, said concentric members forming the input circuit for the grid and cathode, and a conducting loop extending within the spaces of the screen electrode-cathode cavity resonator and the grid-cathode input circuit for coupling the same.

16. An electron discharge device comprising an elongated evacuated envelope containing a cathode, a control electrode, a pair of screen and accelerating electrodes, and a collector, all in the order named, a cavity resonator connected between said accelerating electrodes and extending to the walls of the envelope of the device, a first tubular conducting member surrounding the envelope and capacitively coupled to the cathode, a second tubular member surrounding said first tubular member and having an extension surrounding the cathode and the portion of the envelope containing the cavity resonator and collector and capacitively coupled to the cavity resonator through the envelope, said tubular members forming a cavity resonator between the cathode and one of said screen and accelerating electrodes, an input cavity resonator comprising a pair of concentric conductors extending within the screen electrode-cathode cavity resonator, the inner of said concentric conductors being electrically coupled to said control electrode, the outer of said concentric conductors having an aperture and a loop positioned within said aperture and extending within said screen electrode-cathode cavity resonator and between said concentric conductors coupling the screen-cathode cavity resonator and control electrode-cathode input cavity resonator together.

17. An electron discharge device comprising an elongated evacuated envelope containing a cup-shaped cathode, a control electrode, a pair of screen and accelerating electrodes, and a collector, all in the order named, a ring-shaped beam focusing electrode supported on said cathode, a cavity resonator connected between said accelerating electrodes and extending to the walls of the envelope of the device, a first tubular conducting member surrounding the envelope and cup-shaped cathode and capacitively coupled to the cathode, a second tubular member surrounding said first tubular member and having an extension surrounding the cathode and the portion of the envelope containing the cavity resonator and collector and capacitively coupled to the cavity resonator through the envelope, said tubular members forming a cavity resonator between the cathode and one of said accelerating electrodes, an input cavity resonator comprising a pair of concentric conductors extending within the screen electrode-cathode cavity resonator, the inner of said conductors being electrically coupled to said control electrode, and the outer conductor having an aperture and a coupling loop positioned within said aperture and extending within said screen electrode-cathode cavity resonator and between said concentric conductors coupling the screen-cathode cavity resonator and control electrode-cathode input resonator together.

18. An electron discharge device comprising a cathode surrounded in order by a control grid, a pair of accelerating and screen electrodes, and a collector, a tubular extension connected to said cathode and extending from one end thereof, and a tubular extension connected to said control grid and extending in the opposite direction from the cathode tubular extension, concentric hollow extensions extending from both ends of the screen

electrodes and closed at their outer ends providing with said screen electrodes a cavity resonator, an extension at each end of said cavity resonator concentric with said cathode tubular extension and said grid tubular extension forming a screen electrode-cathode circuit and a screen electrode-control grid circuit.

19. An electron discharge device comprising a cathode surrounded in order by a control grid, a pair of accelerating and screen electrodes, and a collector, a tubular extension connected to said cathode and extending from one end thereof, and tubular extension connected to said control grid and extending in the opposite direction from the cathode tubular extension, concentric hollow extensions extending from both ends of the screen electrodes and closed at their outer ends providing with said screen electrodes a cavity resonator, an extension at each end of said cavity resonator concentric with said cathode tubular extension and said grid tubular extension forming a screen electrode-cathode circuit and a screen electrode-control grid circuit, and a cup-shaped tuning condenser slidably supported on the cathode tubular member and capacitively coupled with the tubular extension on the cavity resonator for tuning the screen electrode-cathode circuit.

20. An electron discharge device including an elongated tubular cathode, a control electrode surrounding said cathode, a tubular member extending from one end of said cathode and a second tubular member extending in the opposite direction from said control electrode, a first screening and accelerating electrode comprising a plurality of radially positioned slat like conducting members, and a second screening and accelerating electrode comprising a plurality of radially positioned slat-like conducting members aligned in the same planes as said first slat-like members, concentric tubular conducting members extending from opposite ends of said slat-like accelerating electrodes and closed at their free ends providing a cavity resonator, insulating cup-shaped members sealing the ends of said resonator and insulatingly supporting said cathode and control electrode within said cavity resonator circuit, a collector electrode surrounding said cathode, control electrode and accelerating electrodes and insulatingly supported from the outside of said cavity resonator by means of insulating collars, tubular extensions at each end of said cavity resonator, one of said extensions being coaxial with and surrounding said cathode extension and the other of said tubular extensions being coaxial with and surrounding said control electrode, a tuning condenser comprising a cup-shaped member slidably supported on said cathode extension and capacitively coupled with a cavity resonator extension and forming a tunable cavity resonator for the screen electrode-cathode circuit.

21. An electron discharge device including an elongated tubular cathode, a control electrode surrounding said cathode, a tubular member extending from one end of said cathode and a second tubular member extending in the opposite direction from said control electrode, a first screening and accelerating electrode comprising a plurality of radially positioned slat-like conducting members, and a second screening and accelerating electrode comprising a plurality of radially positioned slat-like conducting members aligned in the same planes as said first slat-like members, concentric tubular conducting mem-

bers extending from opposite ends of said slat-like accelerating electrodes and closed at their free ends providing a cavity resonator circuit, insulating cup-shaped members sealing the ends of said circuit and insulatingly supporting said cathode and control electrode within said cavity resonator circuit, and a collector electrode surrounding said cathode, control electrode and accelerating electrodes and insulatingly supported from the outside of said cavity resonator circuit by means of insulating collars, tubular extensions at each end of said cavity resonator circuit, one of said extensions being coaxial with and surrounding said tubular member extending from said cathode and the other of said tubular extensions being coaxial with and surrounding said second tubular member extending from said control electrode to provide a control electrode circuit, a member movable longitudinally of the second tubular member and having a conducting member slidably mounted in contact with the interior of said second tubular member for tuning the control electrode circuit and a coupling loop extending through a cavity resonator extension surrounding the second tubular member.

22. An electron discharge device including an elongated tubular cathode, a control electrode surrounding said cathode, a tubular member extending from one end of said cathode and a second tubular member extending in the opposite direction from said control electrode, a first screening and accelerating electrode comprising a plurality of radially positioned slat-like conducting members, and a second screening and accelerating electrode comprising a plurality of radially positioned slat-like conducting members aligned in the same planes as said first slat-like members, concentric tubular conducting members extending from opposite ends of said slat-like accelerating electrodes and closed at their free ends providing a cavity resonator, insulating cup-shaped members sealing the ends of said cavity resonator and insulatingly supporting said cathode and control electrode within said cavity resonator, a collector electrode surrounding said cathode, control electrode and accelerating electrodes and insulatingly supported from the outside of said cavity resonator by means of insulating collars, tubular extensions at each end of said cavity resonator, one of said extensions being coaxial with and surrounding said tubular member

extending from said cathode and the other of said tubular extensions being coaxial with and surrounding said second tubular member extending from said control electrode, and a suppressor electrode positioned between said collector electrode and the second screen and accelerating electrode and comprising a plurality of longitudinally extending rod-like members supported at one end by a collar.

23. 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 electrode, and a screen electrode intermediate said control electrode and collector electrode, a conducting member electrically coupled to said cathode electrode, a conducting member electrically coupled to said screen electrode and surrounding said first conducting member and forming with said first conducting member a cavity resonator, a conducting member electrically coupled to said control electrode, and a conducting member surrounding said last conducting member and electrically coupled with said cathode electrode, and means coupling said cavity resonator and said control electrode together.

24. 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 electrode, and a screen electrode intermediate said control electrode and collector electrode, a cavity resonator coupled between said cathode electrode and said screen electrode, and a cavity resonator coupled between said control electrode and said cathode electrode, and means coupling said cavity resonators together.

25. 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 electrode, and a screen electrode intermediate said control electrode and said collector electrode, a cavity resonator coupled between said cathode electrode and said screen electrode, and a second cavity resonator connected between the control electrode and said screen electrode.

ANDREW V. HAEFF.