

July 7, 1942.

L. P. SMITH

2,289,220

ELECTRON DISCHARGE DEVICE

Filed May 8, 1940

2 Sheets-Sheet 1

Fig. 1

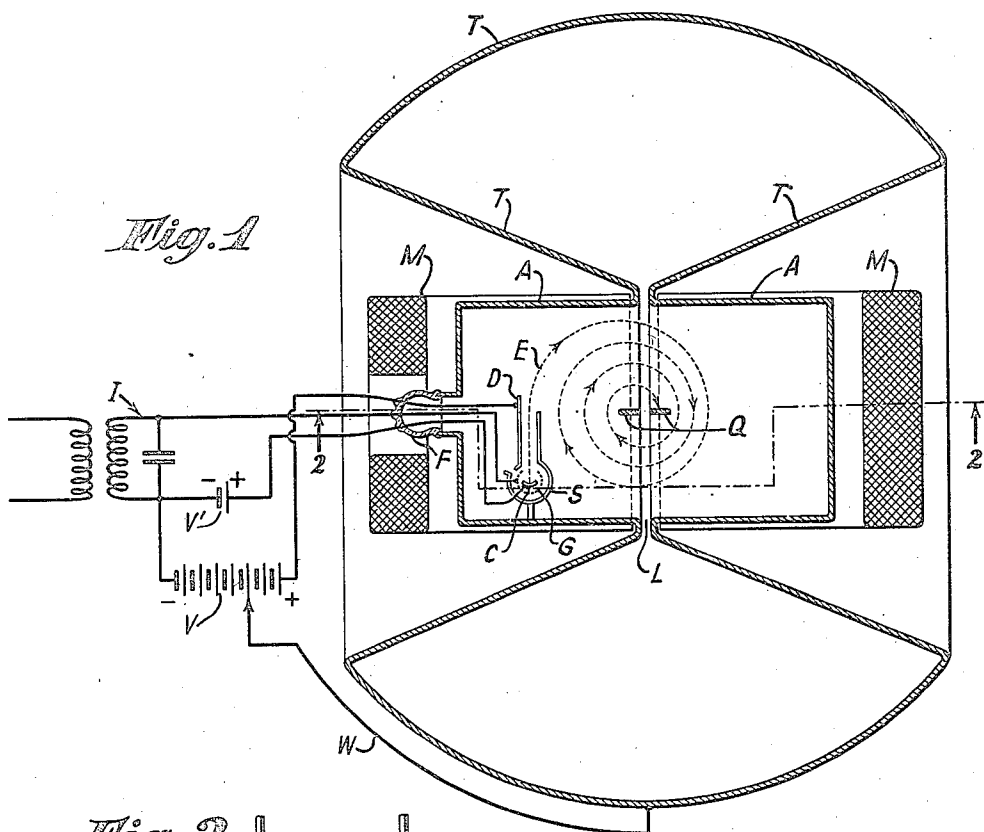
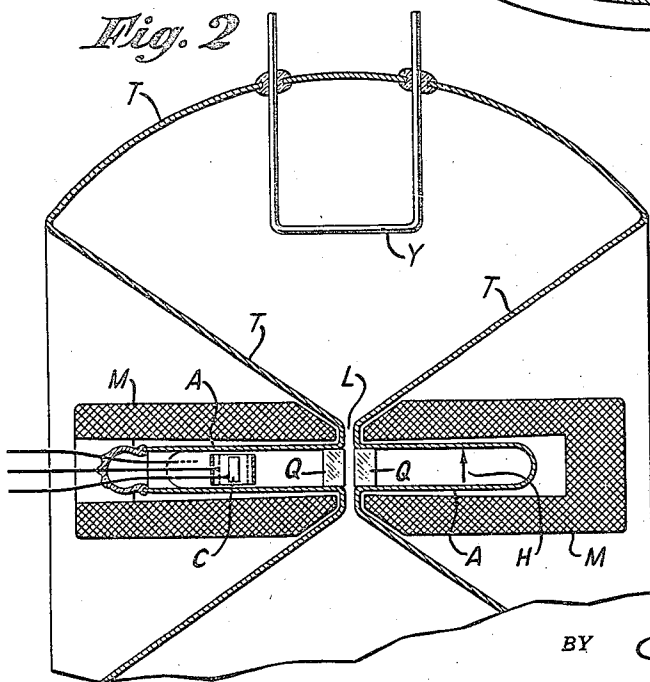


Fig. 2



BY

INVENTOR.
LLOYD P. SMITH

Charles McClair
ATTORNEY.

July 7, 1942.

L. P. SMITH

2,289,220

ELECTRON DISCHARGE DEVICE

Filed May 8, 1940

2 Sheets-Sheet 2

Fig. 5

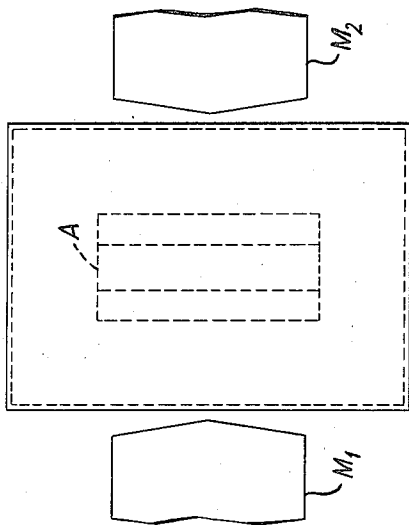


Fig. 3

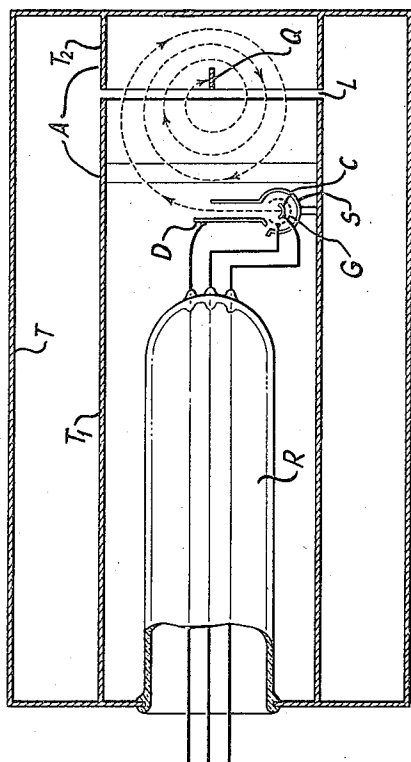


Fig. 4

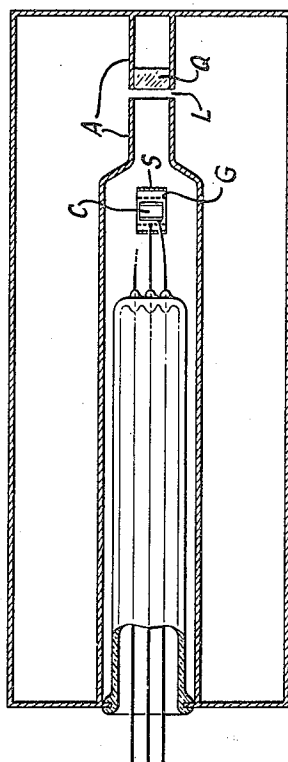
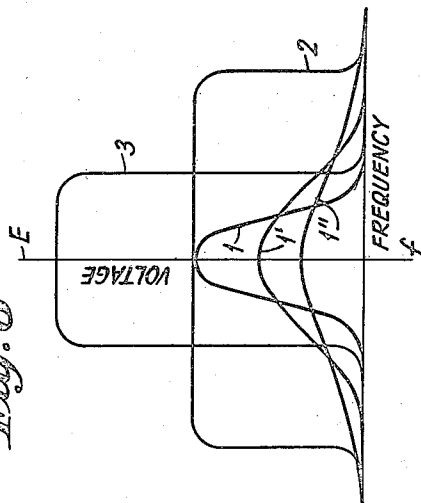


Fig. 6



INVENTOR.
LLOYD P. SMITH
BY *Charles M. Clair*
ATTORNEY.

UNITED STATES PATENT OFFICE

2,289,220

ELECTRON DISCHARGE DEVICE

Lloyd P. Smith, Ithaca, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application May 8, 1940, Serial No. 333,905

10 Claims. (Cl. 250—27.5)

My invention relates to electron discharge devices, more particularly to such devices suitable for use as amplifiers at high frequencies and utilizing the energy made available by decelerating electrons.

The present invention is an improvement over the type of discharge device disclosed in United States Patent 2,096,817 Malter et al., assigned to the Radio Corporation of America, in which by multiply decelerating electrons in a moving stream energy can be abstracted in several successive steps until the velocity of electrons becomes very low. The extracted energy may be utilized to excite tank circuits of novel as well as conventional design.

The type of tube disclosed by the Malter patent referred to above has hollow semi-cylindrical anodes mounted in spaced relation with the open ends opposed to each other and spaced to form a small gap between the open ends. A source of electrons in the form of an electron gun is positioned within one of the anodes adjacent the gap into the interior of the other anode. A magnetic field is directed perpendicularly to the path of the electrons and the transverse surface of the hollow anodes so that the electrons are made to travel in curved paths of decreasing radii, energy being extracted from the electrons during each passage across the gap between the anode segments. An oscillating tank circuit comprising a conventional condenser and inductance may be connected between the two anode segments, the energy extracted from the electrons being applied to the tank circuit causing the tank circuit to oscillate. The electrons are finally removed by one or the other of the two anode segments when sufficient energy is extracted from the moving electrons to prevent further passage across the gap.

It is the principal object of my invention to provide an improved electron discharge device of the type described, suitable for use at very high frequencies and capable of delivering a constant power over a considerable frequency range.

Another object of my invention is to provide such a device and associated circuit which is particularly useful as an amplifier at ultra high frequencies.

A further object of my invention is to produce a device of the kind described having means for successively abstracting energy from a mass of moving electrons by successively reducing the velocity of electrons and utilizing this energy in an absorbing circuit.

A still further object of my invention is to produce such a device utilizing an improved method and means of introducing the electron stream into the device.

5 Another object of my invention is to produce an electron discharge device in which the electrodes of the device are an integral part of the output circuit, improving the characteristics of the tube and associated circuit.

10 A still further object of my invention is to provide such a tube having means for collecting electrons after the energy has been reduced a definite amount and in this manner determining the band width at which the device and associated circuit will operate.

15 A still further object of my invention is to improve the construction of an electron discharge device of the type described so that during operation of the device the electrons will be limited to a path in a given plane so that beam spread and loss of efficiency is prevented.

20 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 Figure 1 is a transverse section of an electron discharge device and associated circuit made according to my invention, Figure 2 is a section taken along the line 2—2 of Figure 1, Figures 3, 4 and 5 are horizontal and vertical transverse sections, and an end view of a modification of an electron discharge device made according to my invention, and Figure 6 is a graph showing the characteristics of conventional tubes and circuits and the tube and circuit made according to my invention.

25 A tube made according to my invention and by which the method of operation described above can be practised is shown in Figures 1 and 2. In Figure 1, the hollow anode conductors A are of rectangular cross section having their open ends oppositely disposed across the gap L. These hollow anode cup-shaped members are electrically connected together and form a chamber with the tank circuit element T—T formed by the surface of revolution of a sector of a circle. Mounted within one of the hollow anode members is a cathode C for supplying electrons, a control grid G and a shielding electrode S electrically connected to the anode. A deflecting electrode D is provided, oppositely disposed with respect to the shield S. It is normally maintained positive enough with respect to the shield S to keep the

path of the electrons straight until it reaches the point E indicated on the drawing. A pair of collector electrodes Q in the form of small flat elongated plates are positioned adjacent the gap and are centrally supported within the anode elements. A magnet M which could be replaced by an electromagnet establishes a magnetic field H perpendicular to the plane of Figure 1 so that electrons emitted by the cathode follow successive circular paths of decreasing radius as indicated by the dotted line. The magnet M is so shaped that the space between the legs is less at the tops adjacent the gap than at the other end. This produces a slight curvature in the magnetic lines of force which keeps the electrons focused in the plane of rotation indicated. The cathode assembly is located such that the center of the first part of the electron path is somewhat to the cathode side of the gap L. The reason for this is that the centers of the succeeding circular paths move toward the gap, so that the cathode assembly is positioned to insure that the electrons do not strike the cathode assembly on the second trip around. The potential of the cathode C is negative with respect to the anode elements A and shield S. The high frequency voltage to be amplified is applied to the control grid G by means of the input circuit I, the bias voltage being provided by the biasing source of voltage supply V' and the voltage for the tank circuit by source V, the connection being made to the tank circuit T by means of conductor W. The lead-in conductors to the various electrodes are sealed-in in one of the anode segments A by means of the cup-shaped sealing member F. The output is taken from the tank circuit by means of the loop Y which extends through and is sealed into the tank circuit as indicated in Figure 2. The magnetic field, of course, is perpendicular to the path of the electrons as indicated by the arrow H.

The operation of the amplifier may be described as follows. When the grid G swings positive with respect to the cathode, a pulse of electrons is given a high energy by the D. C. potential between the cathode C and the shield S which then traverses the circular path as shown. When the pulse crosses the gap L, the oscillating tank circuit T is excited. If the frequency of the pulses liberated by the grid correspond to the resonant frequency of the output circuit, then an intense oscillating electrical field is established in the gap with a phase so related to the harmonic variation in grid voltage that each pulse of electrons experienced a retarding electrical field while crossing the gap. In this way, the electrons give energy to the electro-magnetic field in the output circuit. Since it is a property of the motion of electrons in a uniform field that the period of revolution depends only on the magnetic field intensity and not on the electron energy, the magnetic field can be adjusted so that the time of revolution coincides with the characteristic period of the output circuit. The effective current across the gap is equal to the initial current times the number of times the electrons cross the gap before they lose all of their energy. The electrons will continue to lose energy until their residual is less than that required to cross the gap, in which case their direction of motion will be reversed and they will begin to remove energy from the electromagnetic field. Since a low energy corresponds to a small radius, the electrons may be removed before their energy becomes too low to cross the gap by means of the two baffles Q connected directly to the electrodes

A. The length of these baffles has an important bearing on the band width of the amplifier as will be pointed out below.

A modification of the above construction in which the tank circuit comprises a quarter-wave concentric line tank circuit is disclosed in Figures 3 and 4. The tank circuit comprises the outer tubular member T and the inner tubular member comprising the two sections T₁ and T₂. These two members provide the anode segments A which are separated by the gap L. The tank circuit is sealed to provide a vacuum by means of the reentrant glass portion R which provides the stem. The shape of the magnets M₁ and M₂ may best be seen in Figure 5. This is to provide the type of field provided by the magnet M in Figures 1 and 2, that is—they produce a slight curvature in the magnetic lines of force which keep the electrons focused in a given plane of rotation.

In Figure 6 is shown a graph in which the output voltage is plotted against the frequency in order to show the frequency response of a conventional tube and circuit and a tube and circuit made according to my invention. Curve 1 represents the frequency response of a tube associated with a circuit having certain values of capacitance, inductance and parallel resistance. It will be noted that as the resonant frequency f is approached the voltage is at a maximum but as the frequency of the applied voltage departs from the resonant frequency the voltage in the circuit and hence the output power falls off rapidly. While the circuit can be made less selective by reducing the value of parallel resistance the maximum output voltage will be considerably reduced as shown by curves 1' and 1''. In other words if a constant voltage of variable frequency is applied to the control grid of a conventional amplifier tube, having a cathode and anode, the anode being connected to the usual output circuit having capacitance, inductance and resistance, the effective output voltage falls off rapidly as the frequency of the applied voltage departs from the resonant frequency.

In a device made according to my invention, however, a characteristic such as shown by curve 2 may be readily obtained. The output voltage and hence the output power remains practically constant over a wide frequency range and decreases rapidly near the limits of this range. The explanation of this characteristic lies in the fact that as the applied frequency departs from the resonant frequency f , the number of rotations of electrons within the hollow anodes increases so that the effective total electronic current across the gap increases. Over the flat portion of the characteristic an increase in effective current is very nearly balanced by the increase of phase angle between the output voltage and current in such a manner as to maintain nearly constant the output voltage and power. As the signal frequency departs from the frequency of rotation of electrons (the latter frequency is determined by the strength of the magnetic field) the number of electron transits increases because the electrons will arrive at the gap not at the instants of maximum voltage but at some earlier or later time and hence will not be decelerated as much during each transit through the gap. As a result the greater the phase angle difference between the current pulses and the voltage at the gap the less will be the energy extracted from each electron as it passes across the gap so that each successive circular path while it is smaller is not smaller to the same extent as when the

electrons pass the gap at the resonant frequency of the circuit. The total energy extracted from all the electrons for out of phase operation will be the same as for in phase operation so that the output voltage is maintained at substantially the same value within wide limits from the resonant frequency. The increase in the number of transits made compensates for the reduced energy abstracted on each transit. The frequency range within which these conditions will prevail depends primarily upon the number of transits selected for in-phase operation and upon the natural band width of the loaded output circuit. The greater the band width of the output circuit and the smaller the number of electron transits under in-phase condition, the greater will be the frequency ranges of the tube.

A mathematical analysis of operation of the device shows that the relationship between the frequency range (Δf), the number of electron transits for in-phase operation (P_0) and the circuit parameter K , can be expressed as follows:

$$\frac{\Delta f}{f} = \sqrt{\frac{8}{\pi P_0 K}}$$

where f is the resonant frequency of the circuit (equal to the rotation frequency of electrons);

$K = 2(2\pi f) RC$

R = parallel impedance of the loaded output circuit

C = effective output capacitance.

When the selectivity of the circuit is known (the value of K is given), and the band width of (Δf) requirement is given, then the number (P_0) of electron transits at resonance can be determined from the above equation, and the length of the baffles Q in Figure 1 can be adjusted to permit this number of transits for a given voltage on the anode.

The maximum possible band widths for constant output is of the order of 8% of the operating frequency.

Thus, an amplifier such as described above has the advantages summarized below—

1. The delivery of constant power over a wide frequency range even though the output circuit into which it operates is selective.
2. Negligible coupling between input (grid-cathode) circuits and the output circuit.
3. A high effective gap current with relatively small initial current to control.
4. Gives high output power for low gap voltage without large initial beam current.
5. Capable of operating at 500 megacycles or higher.

It will thus be seen that a tube made according to my invention provides practically ideal characteristics for a tube intended for use at ultra high frequencies and for amplification of signals in circuits covering a wide range of frequencies, and is particularly suited for use in frequency modulated systems.

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 pair of hollow conducting members separated by a gap and having openings oppositely disposed across said gap, means within one of said hollow conducting members for projecting a stream of electrons parallel to said gap, said means being positioned within said one of said hollow conducting members and spaced away from said gap, means for causing said stream of electrons to follow curved paths of decreasing radii across said gap and a hollow resonant tank circuit connected to said hollow conducting members for absorbing energy from said stream of electrons.

2. An electron discharge device having a pair of hollow conducting members separated by a gap and having openings oppositely disposed across said gap, means within one of said hollow conducting members for projecting a stream of electrons parallel to said gap, said means being positioned within said one of said hollow conducting members and spaced away from said gap, means for causing said stream of electrons to follow curved paths of decreasing radii across said gap and a tank circuit connected to said hollow conducting members for absorbing energy from said stream of electrons and electrode means adjacent said gap within one of said hollow conducting members for absorbing electrons when the energy of the moving electrons is decreased to a predetermined amount.

3. An electron discharge device having a pair of hollow conducting members separated by a gap and having openings oppositely disposed across said gap, means within one of said hollow conducting members for projecting a stream of electrons parallel to said gap, said means being positioned within said one of said hollow conducting members and spaced away from said gap, means for causing said stream of electrons to follow curved paths of decreasing radii across said gap and a tank circuit connected to said hollow conducting members for absorbing energy from said stream of electrons, and a collector electrode comprising a flat member lying in a plane transverse to the electron paths and positioned adjacent the gap for absorbing electrons, the energy of which has been reduced to a predetermined amount for determining the band width at which said device and circuit will operate.

4. An electron discharge device including a pair of hollow anode members having openings oppositely disposed across a gap, an electron source for supplying a stream of electrons comprising a cathode and a control electrode adjacent the cathode, and a shield surrounding said cathode and control electrode, the stream of electrons being projected within one of said hollow anode members parallel to said gap, a tank circuit connected between said hollow anode members, means for causing electrons to traverse said gap in circular paths of decreasing radii, and electrode means adjacent the gap for extracting electrons from said stream of electrons when the energy of the electrons has been reduced to a predetermined amount.

5. An electron discharge device including a pair of hollow anode members having openings oppositely disposed across a gap, an electron source for supplying a stream of electrons comprising a cathode and a control electrode adjacent the cathode, and a shield surrounding said cathode and control electrode, the stream of electrons being projected within one of said hol-

low anode members parallel to said gap, a tank circuit connected between said hollow anode members, said tank circuit including a hollow member formed by a surface of revolution of a sector of a circle, means for causing electrons to traverse said gap in circular paths of decreasing radii, and electrode means adjacent the gap for extracting electrons from said stream of electrons when the energy of the electrons has been reduced to a predetermined amount.

6. An electron discharge device including a pair of hollow anode members having openings oppositely disposed across a gap, an electron source for supplying a stream of electrons comprising a cathode and a control electrode adjacent the cathode, and a shield surrounding said cathode and control electrode, the stream of electrons being projected within one of said hollow anode members parallel to said gap, a tank circuit connected between said hollow anode members, said tank circuit including a hollow member formed by a surface of revolution of a sector of a circle, said tank circuit and hollow anode members being integral with each other, means for causing electrons to traverse said gap in circular paths of decreasing radii, and electrode means adjacent the gap for extracting electrons from said stream of electrons when the energy of the electrons has been reduced to a predetermined amount.

7. An electron discharge device having a pair of hollow conducting members separated by a gap and having openings oppositely disposed across said gap, means within one of said hollow conducting members for projecting a stream of electrons parallel to said gap, said means being positioned within said one of said hollow conducting members and spaced away from said gap, means for causing said stream of electrons to follow curved paths of decreasing radii across said gap and a tank circuit connected to said hollow conducting members for absorbing energy from said stream of electrons, and magnetic means comprising U-shaped magnet members each receiving one of said hollow conducting members, the hollow conducting members being disposed between the legs of said magnet members.

8. An electron discharge device having a pair of hollow conducting members separated by a gap and having openings oppositely disposed across said gap, means within one of said hollow conducting members for projecting a stream of electrons parallel to said gap, said means being positioned within said one of said hollow

conducting members and spaced away from said gap, means for causing said stream of electrons to follow curved paths of decreasing radii across said gap, a tank circuit connected to said hollow conducting members for absorbing energy from said stream of electrons, magnetic means comprising U-shaped magnet members each receiving one of said hollow conducting members, the hollow conducting members being disposed between the legs of said magnet members, the inside surface of the legs of said magnets being more closely disposed adjacent the gap than at the surface of the hollow conducting members farthest away from said gap.

9. An electron discharge device including a pair of hollow anode members having openings oppositely disposed across a gap, an electron source for supplying a beam of electrons within one of said anode members and initially directed parallel to said gap and comprising a cathode and a control electrode adjacent the cathode, and a shield surrounding said cathode and control electrode, a tank circuit connected between said hollow anode members, means for generating a magnetic field for causing electrons to traverse said gap on circular paths of decreasing radii, and means adjacent the gap for extracting electrons from said stream of electrons, and an auxiliary electrode parallel to the gap for neutralizing the effect of the magnetic field on the electron beam within a predetermined area within one of said anode members.

10. An electron discharge device including a pair of hollow anode members having openings oppositely disposed across a gap, an electron source comprising a cathode and a control electrode adjacent the cathode for supplying a stream of electrons initially directed parallel to said gap within one of said hollow anode members, and a shield surrounding said cathode and control electrode, a tank circuit connected between said hollow anode members, said tank circuit comprising a quarter wave concentric line, the inner member of which forms the hollow anode segments separated by the gap, means for causing electrons to traverse said gap on circular paths of decreasing radii, said means comprising a pair of magnets outside of said concentric line and positioned on opposite sides of the electron discharge device for inducing a magnetic field perpendicular to the path of the electrons, and means adjacent the gap for extracting electrons from said stream of electrons.

LLOYD P. SMITH.