

April 22, 1941.

A. V. HAEFF

2,239,421

ELECTRON DISCHARGE DEVICE

Filed March 9, 1940

3 Sheets-Sheet 1

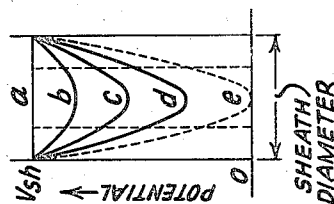
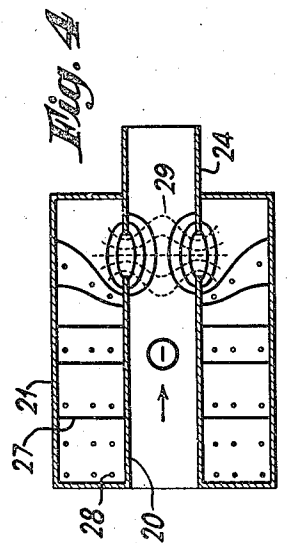
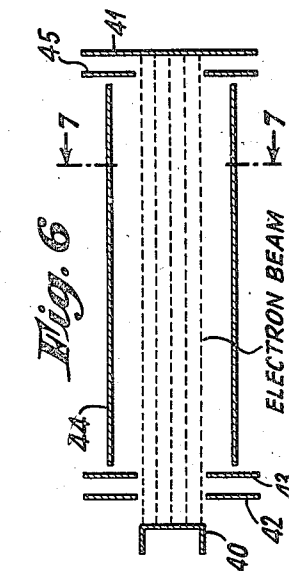
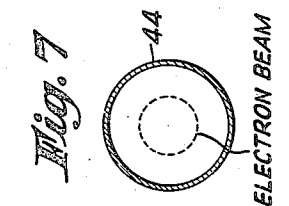
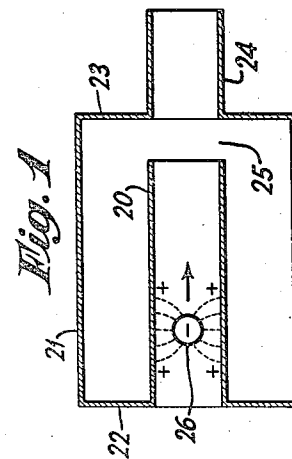
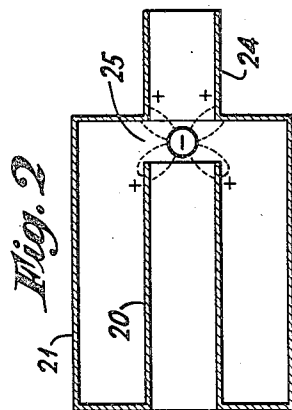
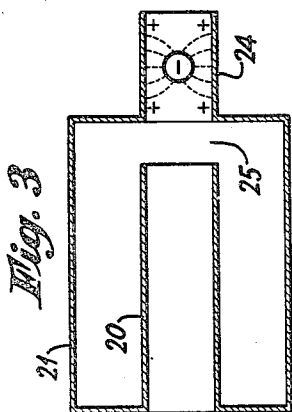
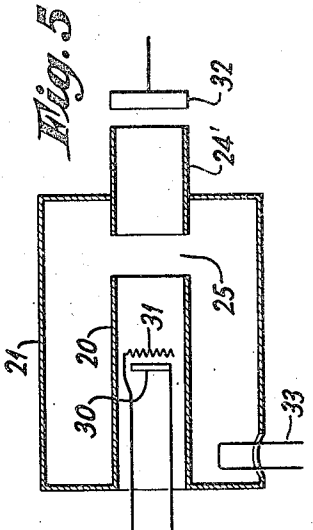


Fig. 8

a - $I = 0$
b - $I < I_{max}$
c - $I = I_{max}$
d - $I = I_{max}$
e - $I > I_{max}$



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Fig. 9

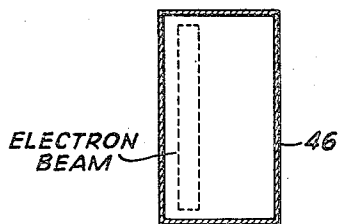


Fig. 10

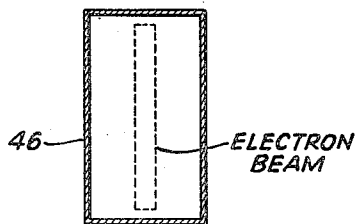


Fig. 11

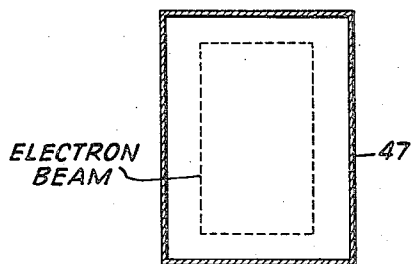


Fig. 13

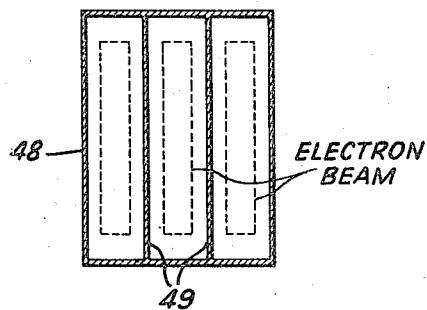


Fig. 12

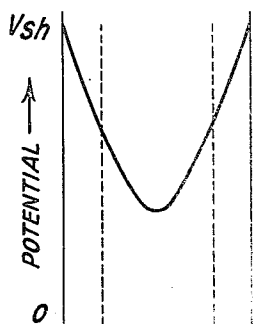
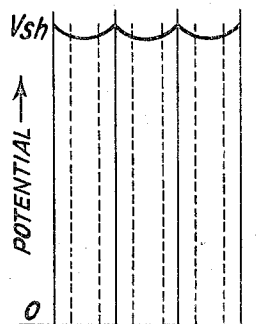


Fig. 14



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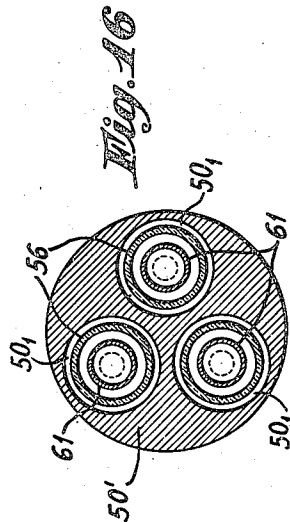
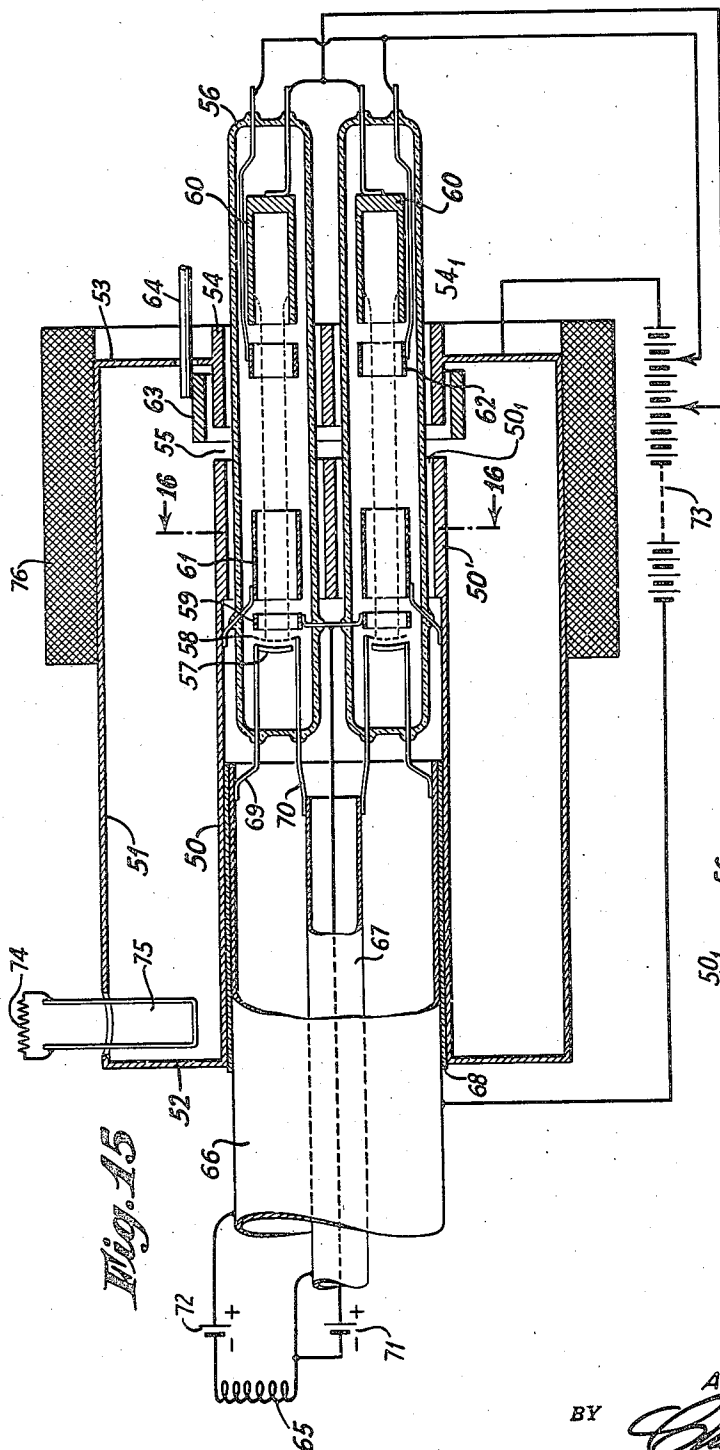
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3 Sheets-Sheet 3



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2,239,421

ELECTRON DISCHARGE DEVICE

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Application March 9, 1940, Serial No. 323,072

5 Claims. (Cl. 250—27.5)

My invention relates to electron discharge devices, particularly to such devices suitable for use at high frequencies.

It is well known that conventional tubes become inoperative at very high frequencies. The principal difficulties which prevent operation at high frequencies are due chiefly to the following factors, that is, the finite electron transit time producing abnormal loading of the input circuit and loss of transconductance of the tube, difficulty in obtaining necessary small coupling between the output electrode and the input electrode which results in regeneration or excessive loading of the output circuit due to the reflected input losses and the consequent loss of power output and efficiency, and increased losses in the circuit due to the presence of large circulating currents at high frequencies and due to an increase in effective resistance of the circuit.

In my copending application Serial No. 254,239 filed February 2, 1939, and assigned to the same assignee as the present application I show an improved electron discharge device particularly suitable for use at high frequencies and in which electron transit time is not critically related to the period of oscillation, which will function satisfactorily at frequencies at which conventional tubes fail to operate, and in which high frequency losses are minimized, this tube being particularly suitable for use as an amplifier at very high frequencies.

Briefly, a tube of this type includes a concentric line tank circuit comprising an outer cylinder and a pair of coaxial inner tubular members spaced axially to provide a gap, the outer cylinder being electrically connected at its end to the two inner tubular members by discs. A cathode and control grid for supplying a modulated beam of electrons and a collector electrode for collecting the modulated beam are positioned within the inner tubular members so that the gap lies between the cathode and collector electrode whereby the modulated beam must move across the gap and thus induce a voltage in the tank circuit.

One of the difficulties encountered with tubes utilizing electron beams has been the effect of the space charge. Space charge causes lowering of space potentials between the cathode and anode or collector and sets an upper limit to the perveance of the electrode system changing the electron velocity distribution over the cross section of the beam, which may give rise to hysteresis effects. Perveance is a constant which can be expressed as the ratio of the current to or through an electrode with respect to the volt-

age on that electrode to the three halves power. It is a convenient means of comparing tubes from an engineering standpoint and its value depends to a great extent upon the emitting cathode area, the spacing between the tube electrodes, and the electrode configurations in so far as these facts affect the cathode current. In a tube of the type described the radio frequency field from the deceleration gap of the output circuit makes it necessary to use a long beam path to prevent coupling between the output and input circuits and also increases the effective length of the deceleration gap, limiting the effectiveness of the transfer of energy from the electron beam to the output tank circuit.

It is therefore the principal object of my invention to provide an electron discharge device of the type described above utilizing an electron beam in which the ill effects of the space charge is substantially reduced or eliminated.

It is another object of my invention to provide such a device having improved characteristics whereby the efficiency of the device is increased.

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 to 4 inclusive are schematic diagrams illustrating the principles of operation of an electron discharge device to which my invention is applied, Figure 5 is a simplified diagrammatic representation of an electron discharge device employing these principles of operation, Figures 6 to 14 inclusive are diagrams illustrating other principles of operation of electron discharge devices employing electron beams and illustrating the principles of my invention, Figure 15 is a longitudinal section of an electron discharge device made according to my invention and its associated circuit, and Figure 16 is a transverse section along 16—16 of Figure 15.

A better understanding of my invention can be had by discussing the principles involved. To illustrate these principles involved reference is had to Figures 1 to 4 inclusive. In Figure 1 is schematically shown the longitudinal schematic section of a quarter wave concentric line tank circuit comprising an inner tubular conductor 20 which may be cylindrical in cross section, and a hollow outer tubular conductor 21 concentric with the inner conductor 20 and electrically connected to the inner conductor 20 by the conducting plate 22. A second tubular conductor 24 which may be

referred to as the aperture extension is coaxial with the conductor 20 and spaced axially from the conductor 20 to provide a gap 25. This tubular conductor 24 and the outer conductor 21 are connected by the conducting plate 23. This arrangement provides a quarter wave concentric tank circuit. If a negatively charged body 26 is projected axially through the inner conductor 20 from left to right, the conditions of the charge distribution on the circuit as the body 26 is moved along the interior on conductors 20 and 24 is indicated in Figures 1 to 4 inclusive. As shown in the figures, there is a positive charge, equal to the negative charge induced on the inside of the inner conductor near the body. However, initially no charge appears on the outer surface of the inner conductor 20. The induced charge moves with the charged body along the inner surface of conductor 20 until the end of the inner conductor 20 is reached. During the passage of the charged body across the gap 25, the charge is partially imaged on the end of the inner conductor 20 and partially on the outer conductor 24 as shown in Figure 2. The passage of the charged body beyond the gap 25 into the conductor 24 causes the induced charge all to appear on the inner surface of the conductor 24 as shown in Figure 3. The induced charge in transferring from the end of the inner conductor to the conductor 24 flows back over the outer surface of the inner conductor 20 and the inner surface of conductor 21, thus constituting a current flow in the quarter wave tank circuit. If charged bodies are projected past the gap in proper phase and frequency relationship with respect to the resonant frequency of the tank circuit, the circuit may be made to oscillate vigorously merely by the passage of the charged bodies past the gap.

Figure 4 illustrates the configuration of the electric and magnetic fields within the resonant space of the tank circuit when the latter is excited. The solid lines 27 represent the electric field distribution and the circles 28 represent the magnetic lines of force. The dashed lines 29 represent the equipotential surfaces in the gap. Along the major part of the length of the tank circuit the direction of the electric field is substantially radial. However, at the gap 25 the electric field has an axial component. The electric field does not penetrate very far inside the open end of the inner conducting member 20 or inside the conductor 24, but is confined effectively to the space defined approximately by the limiting equipotential lines 29 shown in the figures. The space inside the inner conductor 20 and inside the conductor 24 is essentially field free, therefore no work will be done on a charge moving inside the inner conductor 20 by the electric field until the charge reaches the gap 25. If the charge traverses the gap at the instant when the electric force is in the direction from 20 to 24, the charge will be decelerated, its energy being given up to the tank circuit. A charge crossing the gap during the opposite half cycle when the field is reversed will be accelerated and absorb energy from the circuit. If, however, the number of charges traversing the gap during the first half cycle is greater than during the second, the net effect will be that energy is supplied to the tank circuit.

Thus, the tank circuit may be excited by passing groups of electrons at the proper frequency across the gap between the conductors 20 and 24. The motion of the electrons in the interior of

the inner conductor 20 has no effect on the current in the tank circuit. Also high frequency electromagnetic fields which will be generated within the resonating space of the tank circuit penetrate but a short distance inside the conductor 20 and conductor 24 which act as a screen electrode so that the electrons will be influenced by these fields only during their passage across the gap.

In Figure 5 is shown schematically in section an electrode arrangement of a tube embodying my invention and operating on the principle described above. Mounted within the inner conductor 20 is a conventional cathode 30 and a grid 31, which supply the pulses of electrons in the proper phase relation necessary to excite the tank circuit. A collector electrode 32 may be placed beyond the screening electrode or aperture extension 24'. If now a high potential is applied between the cathode and the tank circuit including electrodes 20 and 24' and also between the collector 32 and cathode 30, a stream of electrons from the cathode will bow toward the collector. If a high frequency voltage is applied between the control grid and the cathode the electron stream will be periodically modulated in intensity. Pulses of electrons traversing the gap 25 will induce high frequency currents between the electrodes 20 and 24'. If the excitation frequency is adjusted to the resonant frequency of the tank circuit a high impedance will exist across the gap 25 at this frequency. The induced currents, therefore, will produce a high radio frequency voltage across the gap 25. The phase of this voltage at or near resonance will be such as to decelerate electrons traversing the gap during the half period of maximum intensity of the electron current in the stream.

The energy lost by the electrons is transformed by the tank circuit into the energy of the electromagnetic field within the resonating space between the inner and outer conductors and then may be conveyed to the useful load by means of a coupling loop such as, for example, 33 extending through an aperture in the outer tubular conductor 21 of the tank circuit.

The high frequency electromagnetic field existing in the resonant space of the tank circuit penetrates only a short distance inside the tubular electrode 20 and inside the tubular screen electrode 24. Therefore, by positioning the control electrode 31 at a suitable distance from the gap 25 the coupling between the input electrodes 30 and 31 and the output electrodes 20 and 24' can be reduced to a negligible value. The collector electrode is also placed at an adequate distance from the gap to minimize coupling between it and the tank circuit. This results in a reduction of the losses caused by the absorption of radio frequency energy from the tank circuit by the collector.

To minimize the transit time effects the electrodes 20 and 24' can be operated at suitable high potentials with respect to the cathode. The adjustment of these potentials is not critical because the functioning of the tube does not depend critically upon the electron transit time. This is because the electrons are effective in exciting the output circuit only during the short period of time that they pass through the field extending through the gap 25. The current collecting electrode 32 can be operated at a much lower potential than the conductors 20 and 24 and in order to obtain a high efficiency it is usu-

ally operated at a potential just sufficient to collect all decelerated electrons. To improve the functioning of the device an electrostatic or magnetic focusing of the electron stream can be utilized to prevent electrons from impinging on the high potential electrodes 20 or 24. Thus these electrodes will not dissipate energy and all of the power generated in the tube will be supplied by the low voltage collector power supply.

To illustrate the problem involved in utilizing electron beams in tubes above described and the solution provided by my invention, reference is had to Figures 6 to 14 inclusive. In the electrode arrangement shown in Figure 6 the cathode 40 supplies a beam of electrons, which is collected by the anode or collector 41. The beam may be formed by electrode 42 which may be at a positive or negative potential with respect to the cathode 40 and may, if desired, be modulated by the electrode 43 before passing through the sheath electrode 44 and the shielding electrode 45. The electrodes 43 and 45 may both be shield electrodes and the beam controlled by the electrode 42. This sheath electrode 44 is preferably maintained at a positive potential with respect to the cathode 40. Figure 7 shows the relation of the beam and sheath transversely of the sheath. As shown in Figure 8 with no current flowing through the sheath the space potential inside the sheath is uniform as indicated by the line *a*. As the beam current is increased the space potential will decrease. The distribution of the space potential across the beam for different values of the injected current is shown by lines *b*, *c* and *d*. Curve *d* represents the distribution for the maximum current flow. If the injected current is increased above this maximum current the space potential will drop discontinuously to zero at the center of the beam at some point along the length of the beam, thus forming a virtual cathode at that point. Partial electron reflection from the virtual cathode will result in a decrease of the collected current with further increase in the injected current. The magnitude of the maximum current that can be passed through the sheath electrode depends upon the transverse dimensions and shape of the beam and the sheath electrode, upon the current distribution over the cross section of the beam and is proportional to the $\frac{3}{2}$ power of potential of the sheath electrode. If the sheath electrode is long compared to its opening and the beam cross section is kept constant by proper focusing, such as by a magnetic field in the direction of electron flow, then the maximum current does not depend upon the length of the beam and upon the potential of the end electrodes. The perveance G_{sh} of the sheath electrode can be defined as the ratio of maximum current to the $\frac{3}{2}$ power of sheath potential, that is

$$G_{sh} = \frac{I_{max}}{V_{sh}^{\frac{3}{2}}}$$

In general, the perveance of the tube can be increased by allowing the electron beam to approach as closely as possible to the sheath electrode. For example, the perveance of an unsymmetrical arrangement of a rectangular beam and sheath, such as shown in Figure 9, is greater than that of Figure 10 where the beam is placed symmetrically with respect to the sheath electrode 46. However, the space charge forces tend

to increase the cross section of the beam so that in order to prevent current absorption by the sheath electrode stronger focusing fields are required when the clearance between the beam and the sheath electrode is made smaller.

In accordance with my invention I provide an effective method of minimizing the effects of space charge. In Figure 11 is shown a sheath electrode of rectangular tubular cross section with a centrally positioned beam of rectangular cross section. The space potential is indicated in Figure 12. In accordance with my invention, as shown in Figure 13, I subdivide the sheath 48 into a plurality of closely adjacent cellular passage ways by longitudinal partitions 49 so that each of the passages or cells passes only a fraction of the total current. The space potential is then that shown in Figure 14 and it will be observed that the depression of the space potential is only slight. Because the perveance of the multi-cellular sheath electrode is proportional to the square of the number of cells for the same total cross section, the potential distribution for the same total current is more uniform throughout the cross section for the multi-cellular electrode. At the same time, the required focusing field is approximately the same for the two cases, because the reduction in the space charge field compensates for the reduced spacing between the beam and the sheath.

An inductive output tube made according to my invention and utilizing the principles discussed above is shown in Figures 15 and 16. This tube makes use of external multi-cellular electrodes. The concentric line tank circuit comprises the outer conductor tubular member 51 and the inner conductor tubular member 50 provided with the electrode portion 50' having the cross section disclosed in Figure 16. A coaxial tubular member 54 having the same cross section as portion 50' is spaced axially to provide the gap 55, the inner and outer tubular members being electrically connected by rings or discs 52 and 53. A plurality of electron beams is directed through the aligned cellular passageways 50; and 54; in the electrode portions 50' and 54 by means of electrode assemblies enclosed within evacuated envelopes 56. Each envelope is positioned within a different pair of aligned cellular passageways to extend therethrough. For supplying electrons, cathode 57, preferably indirectly heated, is mounted at one end of the glass envelope. The control grid 58 and focusing electrode 59 serve to modulate and focus a beam of electrons which is indicated by the dotted lines. Collector 60 is mounted in the other end of the envelope. Positioned between these electrodes are accelerator electrodes 61 and 62. The envelopes containing the electron beam supplying means and control electrodes are so positioned that the modulated beams pass the gap 55 and finally reach the collector electrodes 60. As the modulated electron beams pass the gap 55 a radio frequency voltage is developed across the gap so that the electrons are decelerated and high frequency energy is absorbed from the beams and delivered to the tank circuit as described above. The natural frequency of oscillation of the tank circuit may be varied within limits by varying the capacitance between the electrodes 50' and 54 by means of the capacitance ring 63 adjacent the gap 55, movement being accomplished by means of the rod 64.

The input circuit connected between the cathodes 57 and control grids 58 consists of a tuned

concentric line formed by members 66 and 67 which are electrically insulated from the inner tubular member 50 by means of the insulating sleeve 68. The input line may be excited by a voltage source such as a secondary of a transformer 65. The cathodes are connected to the external conductors 66 by conductors 69 and the grids to the internal conductor 67 by means of the conductors 70. Proper biasing voltages are supplied by voltage sources 71 and 72. Thus the grids are simultaneously controlled so that all beams are modulated simultaneously. The proper voltages are applied to the various electrodes from the voltage source 73, the outer conductor 66 of the input transmission line being at cathode potential. An external load 74 may be coupled to the output tank circuit by means of the coupling loop 75. A solenoid 76 may be employed for preventing divergence of the electron beams on their paths from the cathodes to the collectors.

In addition to minimizing the effects of space charge another desirable result obtained by the practice of my invention is that the multi-cellular structure in a tube of the type described reduces the penetration of the radio frequency field from the deceleration gap 55 of the output circuit through the multiple small openings into the inner space of the conductor 50 where the control and accelerating electrodes are housed. The penetration of radio frequency field in the one-cell structure of comparable dimensions would be considerably greater. Thus it is possible by using multi-cellular structure to reduce the coupling between the output and input circuits without using an excessively long electron path between the cathode and the accelerating gap. At the same time the effective length of the deceleration gap is small and the beam is close to the output electrode so that there is an increase in the transfer of energy from the electron beam to the output circuit.

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 tank circuit including a pair of coaxial tubular members spaced axially from each other to provide a gap between said coaxial tubular members, each of said coaxial tubular members having a plurality of adjacent cellular passages extending therethrough, the passages in one tubular member registering with the passages in the other tubular member, means for projecting a beam of electrons axially of each of said cellular passages across said gap, electrode means for simultaneously modulating all of said beams of electrons prior to their passage across said gap and means for collecting the electron beams after their passage across said gap.

2. An electron discharge device having a tank circuit including an inner tubular member and a concentric outer tubular member, said members being spaced from each other and connected at one end by a conducting plate, a third tubular member coaxial with the inner tubular

member and spaced from the inner tubular member to provide a gap, a conducting member connecting the other end of the outer tubular member to said third tubular member, each of said coaxial tubular members having a plurality of adjacent cellular passages extending therethrough, the passages in one tubular member registering with the passages in the other tubular member, means for projecting a beam of electrons axially of each of said cellular passages in the inner tubular members across said gap, electrode means for simultaneously modulating all of said beams of electrons prior to the passage of the beams across said gap, and means for collecting the electrons in said stream after passage of the electrons across the gap.

3. An electron discharge device including a concentric line output tank circuit having a pair of coaxial tubular members spaced axially to form a gap and a concentric outer tubular member electrically connected at each end to a different one of said coaxial tubular members, each of said coaxial tubular members being provided with cellular passages extending longitudinally of the coaxial tubular members and registering with the cellular passages in the other tubular member, and a plurality of evacuated envelopes, each of said envelopes extending through a different pair of registering cellular passages and containing electrode means at one end of the envelope for providing a modulated electron beam, and a collector at the other end of the envelope and positioned so that the modulated beam supply means and the collector are on opposite sides of said gap.

4. An electron discharge device including a concentric line output tank circuit provided with a pair of coaxial tubular members spaced axially to form a gap and another concentric tubular member connected at each end to a different one of said coaxial tubular members, said coaxial tubular members being provided adjacent the gap with a portion having a plurality of cellular passageways extending longitudinally of the members, the cellular passageways of the tubular members registering with each other, and an envelope extending through each of the cellular passageways in one of the tubular members and through the registering cellular passageway in the other tubular member, each of said envelopes containing a cathode at one end of the envelope for supplying a stream of electrons and a collector at the other end of the envelope, and electrode means for controlling the electrons, the collector and cathode being positioned on opposite sides of the gap between the tubular members and an electrical connection connecting all of the cathodes together, and another electrical connection connecting all of the control electrodes together whereby all of the electron streams may be simultaneously modulated.

5. An electron discharge device including a concentric line output tank circuit provided with a pair of coaxial tubular members spaced axially to form a gap and another concentric tubular member connected at each end to a different one of said coaxial tubular members, said coaxial tubular members being provided adjacent the gap with a portion having a plurality of cellular passageways extending longitudinally of the members, the cellular passageways of the tubular members registering with each other, and an envelope extending through each of the cellular passageways in one of the tubular members and

through the registering cellular passageway in the other tubular member, each of said envelopes containing a cathode at one end of said envelope for supplying a stream of electrons and a collector at the other end of the envelope, and a grid for controlling the electrons, the collector and cathode being positioned on opposite sides of the gap between the tubular members and an electrical connection connecting all of the cathodes together, and another electrical connection connecting all of the control grids to-

gether whereby each of the electron streams may be simultaneously modulated, and a concentric line comprising an inner cylinder and an outer cylinder positioned within and insulatingly spaced from one of the coaxial tubular members of said concentric line tank circuit, the inner cylinder being connected to the control grids and the outer cylinder being connected to the cathodes to provide an input circuit connection for said electron discharge device.

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