

April 20, 1948.

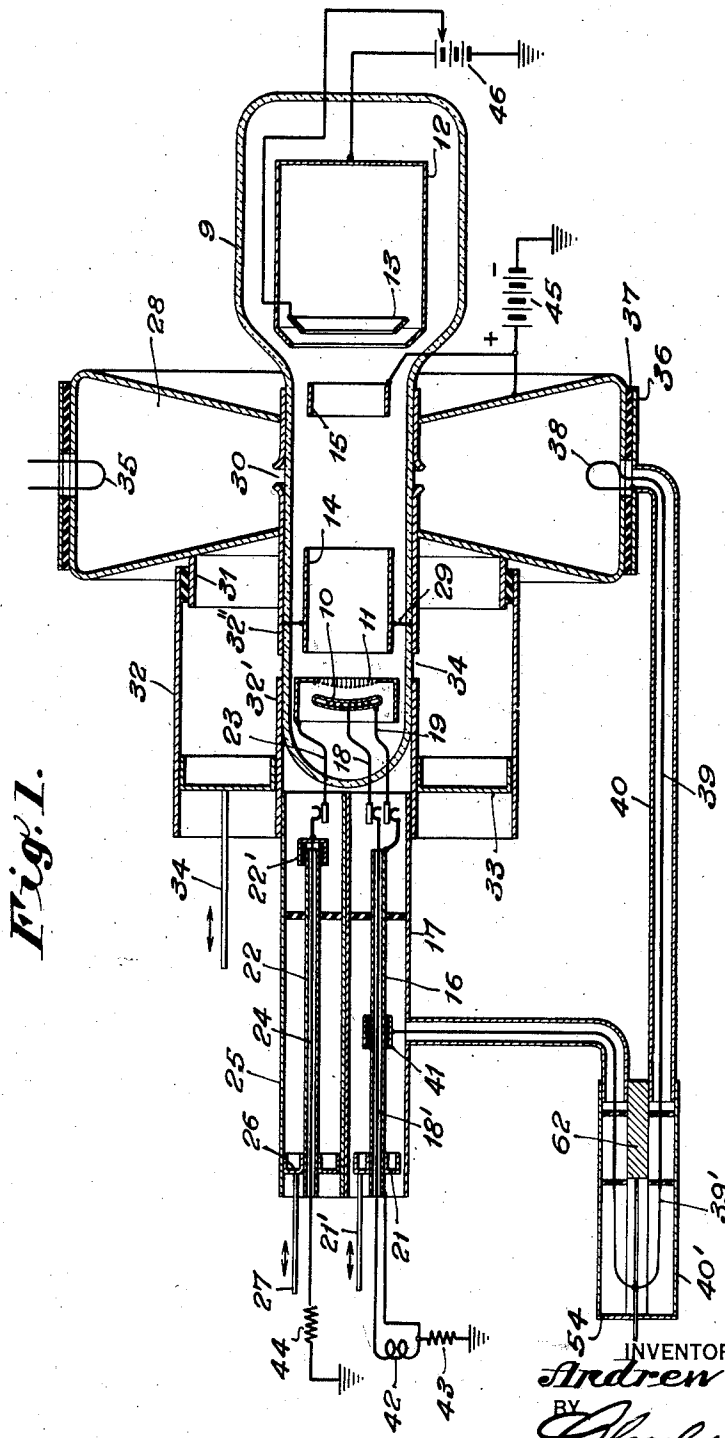
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2,440,089

ELECTRON DISCHARGE DEVICE EMPLOYING CAVITY RESONATORS

Filed Aug. 18, 1942

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

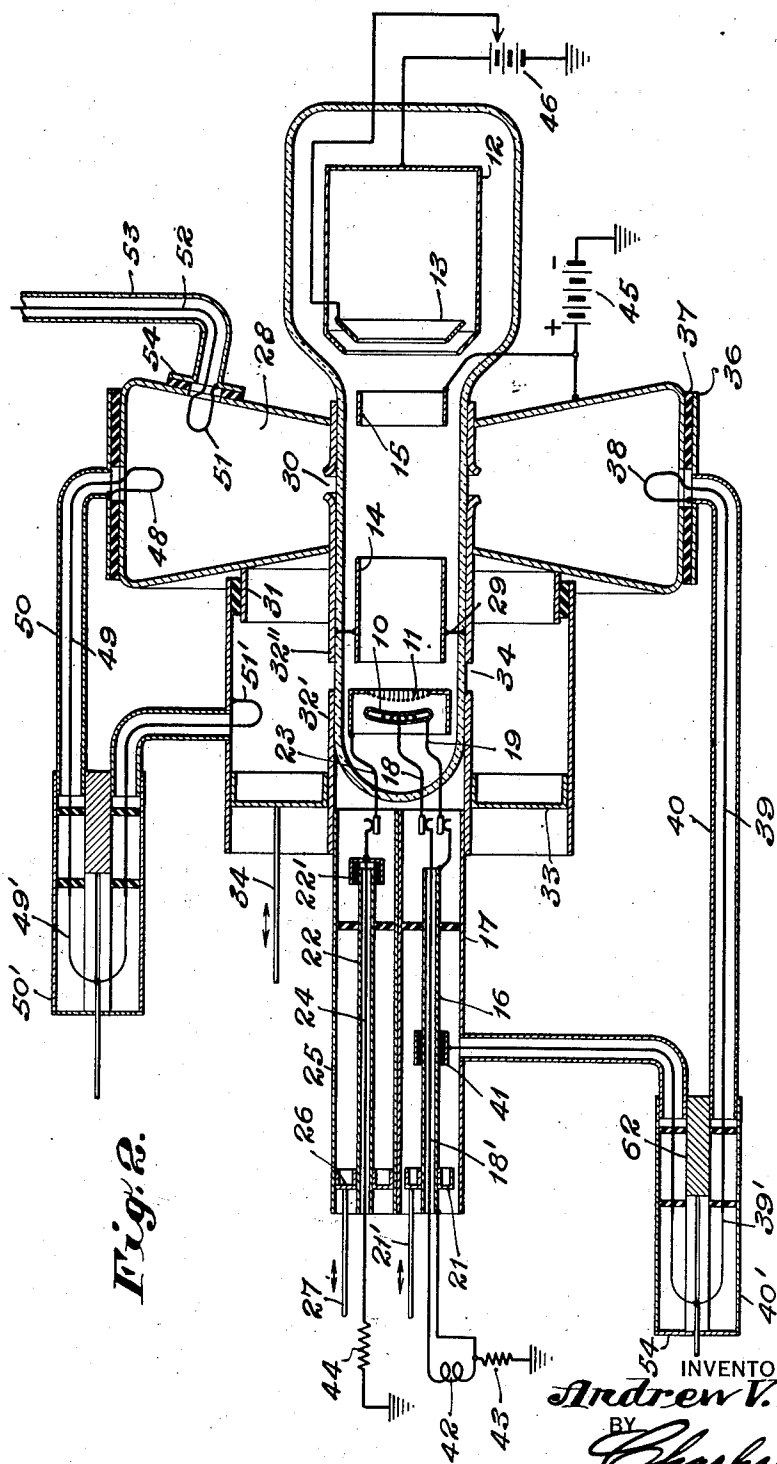


Fig. 2.

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Fig. 3.

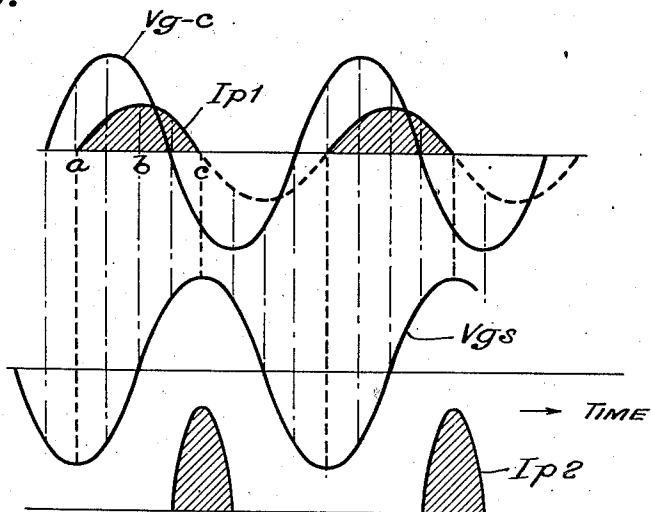


Fig. 4.

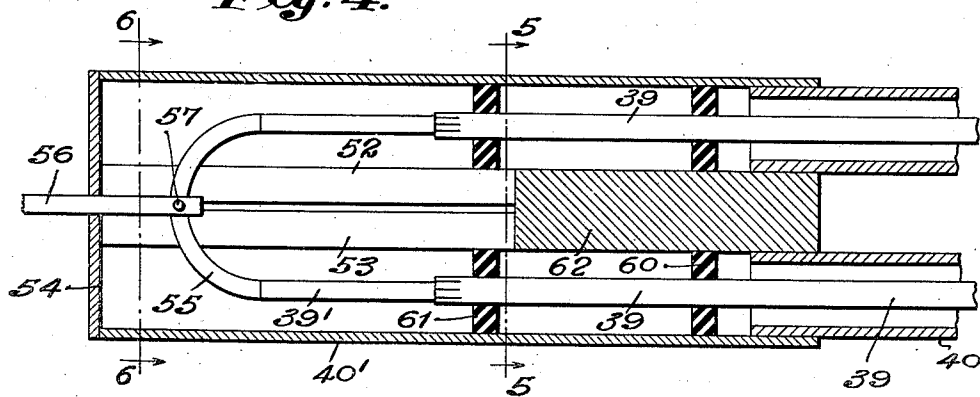


Fig. 5.

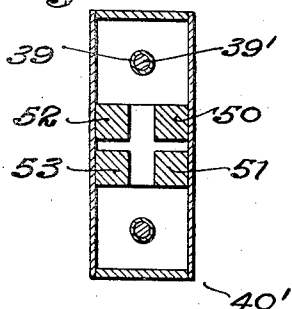
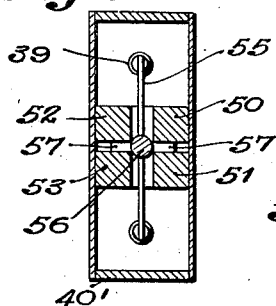


Fig. 6.



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CAVITY RESONATORSAndrew V. Haeff, Washington, D. C., assignor to
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Application August 18, 1942, Serial No. 455,175

15 Claims. (Cl. 315-6)

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My invention relates to electron discharge devices and their associated circuits particularly useful at ultra high frequencies.

In one form of electron discharge device and its associated circuit, an elongated envelope is provided with a cathode and a grid at one end, and at the other end with a collector. Between the cathode and the collector are tubular accelerating electrodes spaced apart to provide a gap past which the electrons move from the grid to the collector. Surrounding the envelope is a resonant cavity circuit or resonator of annular or doughnut shape having a gap registering with the gap between the tubular electrodes and surrounding the envelope close to the envelope wall and lying in a plane transverse to the electron stream. The electrons modulated by the grid and formed into groups of electrons pass across the gap of the resonator and cause the resonator to be energized by induction, the electrons being collected by the collector. When used as an oscillator, energy is fed back from the resonator to the input circuit connected between the cathode and the grid. To insure efficient operation, the voltage which is fed back to the input circuit must be in the correct phase with respect to the input voltage so that losses in the input circuit are compensated for and the oscillations sustained. Due to the length of the path travelled by the electrons and, consequently, due to the finite transit time of the electrons, and various other factors, it is not always possible with the usual means to adjust the phase of the voltage fed back correctly for most efficient operation.

In the type of electron discharge device described, utilizing resonators, maximum power output and efficiency would result if each group of electrons before its passage past the output gap of the output resonator is compressed by application of a velocity modulation potential so as to provide dense groups of small dimensions in the direction of travel of the electrons, and these dense groups made to pass the output gap at the instant of time at which the high frequency voltage across the gap is of such sign and value as to cause a maximum amount of deceleration to each group of electrons.

It is, therefore, an object of my invention to provide an electron discharge device and circuit useful as an oscillator at ultra high frequencies and in which the feedback voltage can be adjusted correctly for most efficient operation.

More specifically it is an object of my invention to provide an oscillator having an adjustable

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coupling means for independently controlling the phase and magnitude of the feedback voltage.

Another object of my invention is to provide a device of the type described and in which the efficiency of operation is improved by compressing electron groups prior to their passage across the output gap.

More specifically it is an object of my invention to provide an electron discharge device and circuit arrangement by means of which a compressing voltage of the correct phase and amplitude influence the electron stream prior to the passage of the electrons past the output resonator gap.

These and other objects will appear hereinafter.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, but the invention will best be understood by reference to the following description taken in connection with the accompanying drawing in which—

Figure 1 is a longitudinal section of an ultra high frequency electron discharge device and circuit made according to my invention;

Figure 2 is a longitudinal section of a modification of the device shown in Figure 1 and its associated circuit;

Figure 3 is a diagram showing the method of operation of electron discharge devices and the associated circuits made according to my invention and shown in Figures 1 and 2;

Figures 4, 5 and 6 show the details of the construction of the adjustable feed back transmission line utilized in the apparatus shown in Figures 1 and 2.

Referring to Figure 1, an electron discharge tube and associated circuit made according to my invention includes the elongated evacuated envelope 9 having at one end a concave surface indirectly heated cathode 10 and a cup-shaped grid 11 having a foraminous portion of the same shape and closely spaced from cathode 10 and formed to shield the cathode from the other electrodes within the tube. Positioned at the other end of the envelope is a collector 12 provided with the secondary electron suppressor electrode 13. Positioned between the grid and the collector are the accelerating electrodes 14 and 15, the electrode 14 being elongated and providing an essentially field-free space within its center portion. Electrodes 14 and 15 also serve as screening electrodes between the output gap and other electrodes of the device.

The cathode circuit comprises the hollow con-

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 ductor 16 surrounded by the conductor 17, thus forming a coaxial line. The cathode is supported by the leads and conductors 18 and 19 which are connected respectively to the conductor 18' within a hollow member 16 by a spring-clip arrangement, and to the exterior of the conductor 16. The conductor 18 serves as a heater lead and the conductor 19 as a cathode and heater lead. The end of the concentric line arrangement is closed by a disc member 21 slidably positioned on a conductor 16 and manipulated by an insulating member 21', a space being provided between the element 21 and the outer conductor 17. By this arrangement the coaxial line is closed for radio frequency currents in effect providing a tunable resonator but the inner conductor 16 and the outer conductor 17 may be maintained at different fixed potentials. The grid circuit includes the inner conductor 22 and the outer conductor 25. The grid lead support 23 is capacitively coupled to the conductor 22 by means of the arrangement shown at 22', but a lead 24 is connected to conductor 23 to permit a biasing voltage to be applied to the grid 11. A closure conductor 26 longitudinally slidable on the conductor 22 is manipulated by an insulating handle at 27. Thus a closed tunable coaxial line resonator is provided for the grid circuit.

Thus, the grid line as well as the cathode line can be separately tuned, and the cathode circuit completely isolated from the other circuits as described more fully below.

The output tank circuit comprises a cavity resonator 28 placed coaxially with the tube and having a gap 30 surrounding the envelope, the gap lying in a plane transverse to the electron stream. Modulated electrons passing across this gap excite the resonator 28 in a manner now well known and described in my United States Patent No. 2,237,878, issued April 8, 1941, and assigned to the same assignee as the present application.

A second resonator having a gap surrounding the electron path between the resonator 28 and the grid comprises the outer conductor 32 and the inner conductors 32' and 32'' closed at one end by the slidable ring-like member 33 and provided with a gap 34 which registers with the gap between the grid 11 and electrode 14. Electrode 14 is electrically connected to the member 32'' by radially directed conductors 29. The capacitance between the conductor 32' and the cylindrical surface of the grid 11 provides a low impedance for high frequency currents between these elements, 32' and 11. Movement of the closure member 33 tunes the control grid-accelerator electrode circuit. Capacitive coupling between the element 32 and the wall of resonator 28 is made by means of the collar 31 to provide a closed control grid-accelerator resonator while at the same time permitting the output resonator 28 to be at a different, preferably higher, fixed potential. The control grid-accelerator electrode resonator when excited by the modulated stream provides compression of the electron groups in a manner to be described below, this compression taking place prior to the passage of electrons across the gap in the output resonator 28.

In order to provide feedback of energy from the output resonator to the input circuit in proper phase, I provide a coaxial feed line adjustable in length and coupled at its ends to the resonator 28 and the cathode coaxial line circuit. Surrounding the resonator 28 is a con-

ducting collar 36 capacitively coupled to the resonator, and insulated therefrom by insulator collar 37. The adjustable coaxial transmission line consists of inner conductor 39 and outer conductor 40, the transmission line being provided with a coupling loop 38 within the output resonator and a capacity coupling element 41 supported on the inner conductor of the coaxial resonator of the cathode circuit. Intermediate the ends of the coaxial feed line is a so-called trombone slide arrangement comprising the elements 39' and 43', details of which are shown in Figures 4, 5 and 6 and which will be described in greater detail below. This permits the physical and consequently the electrical length of the transmission line to be varied to insure proper phase of the energy fed back to the cathode circuit and consequently of the voltage developed between the grid and the cathode.

The output is taken from the output resonator 28 by means of a coupling loop 35. The cathode heater voltage is supplied by voltage source 42. The proper bias on the grid is obtained by the resistor 43 in the cathode circuit and the resistor 44 connected to the grid lead. High positive voltage for the resonator 28 and the accelerating electrode 14 and 15 is supplied by a voltage source 45. The collector is maintained at a lower positive potential than the tank circuit by means of the voltage source 46, the suppressor electrode 13 being at a still lower positive potential than the collector.

Operation of the device, particularly with regard to voltage and current phase relationship and to the action of the compression circuit, can be explained by referring to Figures 1 and 3. The grid 11 is biased negatively with respect to cathode 10 so that the electrons flow from the cathode and through the grid only during the positive half cycles of the radio frequency voltage existing between the cathode and the grid. In Figure 3, the curve designated $v_g - c$ represents the grid-cathode voltage and the curve I_{p1} represents the current passing through the grid 11. As shown there is a small time lag between the voltage peak and the electron current peak which can be ascribed to the transit time of the electrons between the cathode 10 and the grid 11. The current I_{p1} passing through the gap 34 will excite the compressor circuit, which is the control grid-accelerator resonator 32, so that a voltage V_{gs} will be developed across gap 34. The voltage across the gap 34 will be shifted in phase with respect to current I_{p1} is the compressor circuit is tuned off-resonance as indicated by curve V_{gs} of Figure 3. This phase shift is such that the first electrons of the group passing across the gap 34 begin crossing the gap when the radio frequency voltage across the gap is in a direction to oppose movement of the electrons across the gap but increases in a positive direction so that the last electrons crossing the gap are accelerated to the greatest extent. Since the electrode 14 is at a positive potential with respect to grid 11, there is a constant accelerating field across the gap 34. The radio frequency voltage applied by the control grid-accelerating electrode resonator across the gap 34 and which is alternating is superimposed on the fixed accelerator voltage to successively increase or decrease the resultant accelerating voltage. The result is that the electrons of each group are continuously variably accelerated, the last electrons crossing the gap being accelerated to a greater extent than those initially passing across the gap. The electrons

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then pass within the electrode 14 and member 32' within which there is an essentially fieldfree space, before reaching the R. F. field across the gap 30. The operating conditions are so chosen that as the group of electrons passes from the gap 34 to gap 30 and moves through the field-free space, the fast electrons overtake the slow electrons so that the electron group becomes compressed. In Figure 3 these compressed groups are indicated by the deep shadowed areas I_{p2} . The I_{p2} curves as shown in Figure 3 are not related in time to the other curves of Figure 3. The phase of current I_{p2} depends on transit time between gap 34 and 30 during which time compression takes place. In other words I_{p2} is not necessarily in phase with V_{gs} , as shown in Figure 3. The phased feedback voltage and the operating potentials determining electron transit time through different sources are so adjusted that the compressed groups of electrons pass across the gap 30 at the instant of time that the voltage across gap 30 has maximum decelerating effect. Hence there passes a dense charge in a very short period of time at the moment when maximum energy can be delivered to the decelerating field of resonator 28. As a result more power is generated in the output resonator 28 than would be the case with only grid modulation.

In order to prevent coupling between the cathode input circuit and the compressor circuit, the grid circuit is tuned so that the impedance between the inner conductor 32' of the control grid-accelerating electrode resonator and the grid proper can be made substantially zero. This tuning is accomplished by means of plunger 26. The cathode circuit is thus completely isolated and shielded from the remaining circuits of the apparatus and the only coupling is through the feedback transmission line. This prevents any undesired coupling between the control grid-accelerator circuit and the cathode circuit due to common impedances between these circuits. The size of the coupling loop 38 is chosen so as to extract from the output tank circuit 28 the amount of power just sufficient to excite the cathode circuit to the desired amount. The cathode circuit 16-17 is tuned to the operating frequency and the position of the coupling element 41 along the line 16 is adjusted so that the impedance of the cathode circuit at the position 41 is equal to the characteristic impedance of the feedback transmission line 39-40. Under this condition the phase of the feedback voltage is determined solely by the length of the transmission line which is adjustable, and the magnitude of feedback voltage is determined by the size of the coupling loop 38.

A further improvement of my invention is shown in Figure 2, the same elements being designated by the same numerals in both Figures 1 and 2. In the modification shown in Figure 2 an additional adjustable transmission line is connected between the output resonator 28 and the compressor resonator connected between the control grid 11 and the accelerating electrode 14. This serves two purposes, first, it insures that sufficient energy is supplied to the control grid-screen electrode cavity resonator, and, second, it makes it possible to excite the compressor resonator in the correct phase for maximum compression even when this circuit is tuned to resonance at the operating frequency. The transmission line comprises an inner conductor 49 and an outer conductor 50 with coupling loops 51' and 48, the adjustable portion being provided

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by the trombone slide arrangement 49' and 50'. The output of the oscillator is delivered to the useful load by means of a coupling loop 51 and a coaxial feed line 52 and 53. The outer conductor 53 of this line is isolated from the resonator 28 by means of a by-pass condenser 54 in order to remove the resonator 28 voltage from the feed line. The operation of the apparatus shown in Figure 2 is substantially that of the apparatus shown in Figure 1.

The details of the trombone slide arrangement are shown in Figures 4, 5 and 6. It comprises a box-shaped structure of rectangular cross section 40' and inner conductors 39 and 39' formed of hollow tubular and solid rods, respectively. The inner tubular members are supported within the outer box-like structure 40' by insulating supports 60 and 61. The outer box-like structure 40' is divided into two elongated parallel passageways by means of the conducting wall 62 and its extensions 50, 51, 52 and 53. The box-like structure is closed at one end by a partition 54. The members 50, 51, 52 and 53 provide a partition similar in function to the solid wall 62, but separated in the middle for permitting movement of the U-shaped element 55 which is connected to the rods 39'. To vary the length of the line, the inner conductors 39' are telescopically received within tubular members 39. Extensions 39' are secured and connected together electrically by means of the U-shaped element 55 connected and movable by means of the insulating arm 56 which is provided with guide fingers 57 sliding in the slots formed between the elements 50-51 and 52-53. The space between 50-51 and 52-53 is only great enough to permit element 55 to slide between them without contact. Elements 50, 51, 52 and 53 are in effect extensions of wall 62 and serve to prevent leakage of R. F. fields from one passageway to another. Thus, the R. F. fields guided by the conductors 39, 39' travel along one passageway and along the conductor 55 enter another passageway and proceed along conductors 39' and 39. Thus the electrical length of the transmission line is varied by varying only the portion of the inner conductor 39'-55-39'.

An apparatus made according to my invention provides an improved oscillator useful at ultra high frequencies and one in which the efficiency of operation is improved. Use of adjustable coaxial transmission lines insures proper phase of the feed-back energy, and the use of compressor circuit produces a more efficient conversion of D. C. energy into R. F. energy as compared to other types of tubes operated under the same voltage conditions.

While I have indicated the preferred embodiments of my invention of which I am now aware, and have 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 form 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 means including a cathode for supplying a beam of electrons, means for receiving said electrons, a control grid between said cathode and receiving means for modulating said beam of electrons to provide spaced groups of electrons when said

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grid is energized by radio frequency voltage, an accelerating and screen electrode positioned adjacent said control grid, means coupled between said control grid and said accelerating and screen electrode for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group of electrons are accelerated to the greatest extent, means in the path of the electrons for providing a field free space through which said accelerated groups of electrons are directed and in which compression of each group of electrons occurs and a resonator surrounding the path of the beam of electrons for inductively extracting energy from the compressed groups of electrons.

2. An electron discharge device having means including a cathode for supplying a beam of electrons, means for receiving said electrons, a control grid between said cathode and receiving means for modulating said beam of electrons to provide spaced groups of electrons when said grid is energized by radio frequency voltage, an accelerating and screen electrode positioned adjacent said control grid, means coupling said control grid and said accelerating and screen electrode for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group of electrons are accelerated to the greatest extent, means in the path of the electrons for providing a field-free space through which said accelerated groups of electrons are directed and in which compression of each group of said electrons occurs and a resonator surrounding the path of the beam of electrons for inductively extracting energy from said compressed groups of electrons, and means including an adjustable feed back transmission line coupled between said resonator and said coupling means for transferring energy from said resonator to said coupling means.

3. An electron discharge device having means including a cathode for supplying a beam of electrons, means for receiving said electrons, a control grid between said cathode and electron receiving means for modulating said beam of electrons to provide spaced groups of electrons when radio frequency voltage is applied to said control grid, an accelerating and screen electrode positioned adjacent said control grid, means including a first resonator surrounding the path of the beam of electrons and coupled between said control grid and said accelerating and screen electrode for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group of electrons are accelerated to the greatest extent, means in the path of the electron groups for providing a field-free space through which said electron groups are directed and in which compression of each group of electrons occurs and a second resonator surrounding the path of the beam of electrons for inductively extracting energy from said compressed groups of electrons.

4. An electron discharge device having means including a cathode for supplying a beam of electrons, means for receiving said electrons, a control electrode between said cathode and receiving means for modulating said beam of electrons, means coupling said cathode and control electrode for applying radio frequency voltage between said cathode and control electrode to provide spaced groups of electrons, an accelerating

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and screen electrode positioned adjacent said control electrode, means coupled between said control electrode and said accelerating and screen electrode for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group of electrons are accelerated to the greatest extent, means in the path of said electrons for providing a field-free space through which the groups of electrons are directed and in which compression of each group of said electrons occurs and a resonator surrounding the path of the beam of electrons for inductively extracting energy from said compressed groups of electrons, means including an adjustable transmission line coupled between said last resonator and means coupled between said cathode and the control electrode for transferring energy from said last resonator to said means coupled between said cathode and control electrode.

5. An electron discharge device having means including a cathode for supplying a beam of electrons, means for receiving said electrons, a control electrode positioned between the cathode and receiving means for modulating said beam of electrons, a coaxial line connected to said cathode for applying a radio frequency voltage between said cathode and control electrode to provide spaced groups of electrons, an accelerating and screen electrode positioned adjacent said control electrode, a resonator coupled between said control electrode and said accelerating and screen electrode for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group of electrons are accelerated to the greatest extent, means in the path of the electrons for providing a field free space through which said groups of electrons are directed and in which compression of each group of said electrons occurs and a resonator in the path of the compressed group of electrons for inductively extracting energy from said compressed group of electrons, means including a transmission line coupled between said last resonator and the coaxial line for transferring energy from said last resonator to said coaxial line.

6. An electron discharge device having means including a cathode for supplying a beam of electrons, means for receiving said electrons, a control electrode between said cathode and receiving means for modulating said beam of electrons, means coupled to said cathode for applying a radio frequency voltage between said cathode and control electrode to provide spaced groups of electrons, an accelerating and screen electrode positioned adjacent said control electrode, means coupled between said control electrode and said accelerating and screen electrode for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group of electrons are accelerated to the greatest extent, means in the path of the electrons for providing a field-free space through which said groups of electrons are directed and in which compression of each group of said electrons occurs and a resonator through which the groups of electrons are directed for inductively extracting energy from said compressed groups of electrons, means including a transmission line coupled to said resonator and

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ferring energy from said resonator to said means coupled to said cathode, and another transmission line for transferring energy from said resonator to the means coupled between the control electrode and the accelerating and screen electrode.

7. An electron discharge device having means including a cathode for supplying a beam of electrons, a control electrode and collector electrode, said control electrode being positioned between said cathode and collector electrode, a cavity resonator connected between said cathode and control electrode, and a cavity resonator positioned between said control electrode and said collector for extracting energy from said beam of electrons, and a coaxial transmission line connected between said cavity resonators and including an elongated tubular structure, a partition extending along said tubular structure providing a pair of elongated adjacent parallel chambers opening into a passageway at one end, a tubular member within each of said chambers and extending longitudinally of said chambers but out of contact with the tubular structure, and a U-shaped element telescopically engaging and connecting said tubular members and extending through said communicating passageway, said U-shaped member being movable to vary the length of the coaxial transmission line.

8. An electron discharge device having means including a cathode for supplying a beam of electrons, a control electrode and a collector electrode, said control electrode being positioned between said cathode and said collector electrode, a concentric line having an inner and outer conductor connected between said cathode and control electrode, and a cavity resonator positioned between said control electrode and said collector, an adjustable coaxial transmission line coupled between said coaxial line and said cavity resonator and including an elongated tubular structure having a longitudinally extending partition providing a pair of adjacent passageways opening into each other at one end, an inner conducting member supported within each of said passageways and an adjustable member connecting the ends of said inner conducting members to change the length of said transmission line, and a coupling loop connected to one end of said transmission line and within said cavity resonator, and a capacity coupling element connected to the other end of said transmission line and extending within the concentric line and coupled to the inner conductor of the concentric line.

9. An electron discharge device having means including a cathode for supplying a beam of electrons, a collector electrode oppositely disposed to said electron supplying means for receiving said electrons, means between said electron supplying means and said collector electrode for modulating said beam of electrons, a first means for applying a radio frequency voltage between said beam supplying means and said modulating means to provide spaced groups of electrons, a first means in the path of said electrons for applying a voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last electrons of each group are accelerated to the greatest extent whereby said groups of electrons are compressed, a second means positioned between said last means and said collector for extracting energy from said compressed groups of electrons, means including a transmission line connected between the means for extracting energy from the com-

pressed groups of electrons and said first means for transferring energy to said first means, and another transmission line connected between the means for extracting energy from the compressed groups of electrons and said means for continuously and variably accelerating each group of electrons for transferring energy to said last means.

10. An electron discharge device having means including a cathode for supplying a beam of electrons, a control grid adjacent said cathode for modulating said beam of electrons, a coaxial line coupled between said cathode and said grid for applying a radio frequency voltage to said grid to provide spaced groups of electrons, and a collector electrode in the path of the electrons for receiving said electrons, means including a first resonator surrounding the path of the beam of electrons for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last of the electrons of each group of electrons are accelerated to the greatest extent whereby said groups of electrons are compressed, a second resonator between the first resonator and collector for inductively extracting energy from the compressed groups of electrons, and means coupling said second resonator and said coaxial line.

11. An electron discharge device having means including a cathode for supplying a beam of electrons, a collector electrode in the path of the electrons for receiving said electrons, control means between said cathode and said collector electrode for modulating said beam of electrons, and means including a coaxial line for applying a radio frequency voltage between said cathode and said control means to provide spaced groups of electrons, means including a first resonator surrounding the beam path for applying a variable voltage phased with respect to said electrons for continuously and variably accelerating each group of electrons such that the last electrons of each group are accelerated to the greatest extent, means in the path of said electrons for supplying a field-free space through which said groups of electrons are directed and in which compression of each group of electrons occurs, and means including a second resonator between said last means and said collector electrode for extracting energy from said compressed groups of electrons, means including a transmission line connected between the second resonator and said coaxial line for transferring energy to said coaxial line, and another transmission line connected between said second resonator and the first resonator for transferring energy to said first resonator.

12. An electron discharge device having means including a cathode for supplying a beam of electrons, a control grid adjacent said cathode and a collector electrode in the path of said electrons for receiving said electrons, a coaxial line having inner and outer conductors, the inner conductor being coupled to said cathode and the outer conductor to said grid for applying voltage to said grid for supplying spaced groups of electrons, means including a first resonator surrounding the path of electrons for applying a variable voltage phased with respect to said electrons for continuously and variably accelerating each group of electrons, such that the last of the electrons of each group of electrons are accelerated to the greatest extent whereby said groups of electrons are compressed, a second res-

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onator positioned between said first resonator and collector for inductively abstracting energy from the compressed groups of electrons, and means coupling said second resonator and said coaxial line, including a coaxial line.

13. An electron discharge device having means including a cathode for supplying a beam of electrons, a control grid adjacent said cathode for modulating said beam of electrons, and a collector electrode in the path of said electrons for receiving said electrons, a coaxial line coupled between said cathode and grid for applying a radio frequency voltage to said grid to provide spaced groups of electrons means including a first resonator surrounding the path of the beam of electrons for applying a variable voltage phased with respect to said electrons for continuously variably accelerating each group of electrons such that the last of the electrons of each group of electrons are accelerated to the greatest extent whereby said groups of electrons are compressed, a second resonator connected between the first resonator and collector electrode for inductively extracting energy from the compressed groups of electrons, and means coupling said second resonator and said coaxial line, and a second coaxial line coupled to said grid, and a coaxial transmission line connected between said resonators.

14. An electron discharge device having means including a cathode for supplying a beam of electrons, a control grid adjacent said cathode for modulating said beam of electrons, a coaxial line coupled between said cathode and said grid for applying a radio frequency voltage to said grid to provide spaced groups of electrons, and a collector electrode in the path of said electrons for receiving said electrons, means including a first resonator surrounding the path of the beam of electrons for applying a variable voltage phased with respect to said electrons for continuously and variably accelerating each group of electrons such that the last of the electrons of each group of electrons are accelerated to the greatest extent

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whereby said groups of electrons are compressed, a second resonator connected between the first resonator and collector electrode for inductively extracting energy from the compressed groups of electrons, and means coupling said second resonator and said coaxial line, said first resonator having a movable wall for tuning said first resonator.

15. An electron discharge device having an elongated envelope containing at one end a cathode and grid and at the other end a collector electrode, said grid being between said cathode and said collector electrode, a screen and accelerating electrode adjacent said grid, a first resonator surrounding the path of the beam of electrons from the cathode to the collector electrode and positioned between said accelerating electrode and collector electrode, a second resonator surrounding said envelope and coupled between the first resonator and said grid and including a tubular member, a longitudinally movable disc for closing one end of said tubular member whereby said second resonator may be tuned, and a cavity resonator coupled between said cathode and said grid and an adjustable transmission line coupled between said first resonator and the cavity resonator coupled between said cathode and said grid.

ANDREW V. HAEFF.

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