Sept. 3, 1946. J. R. PIERCE 2,406,850

ELECTRON DISCHARGE APPARATUS

Filed April 11, 1941

FIG. 1

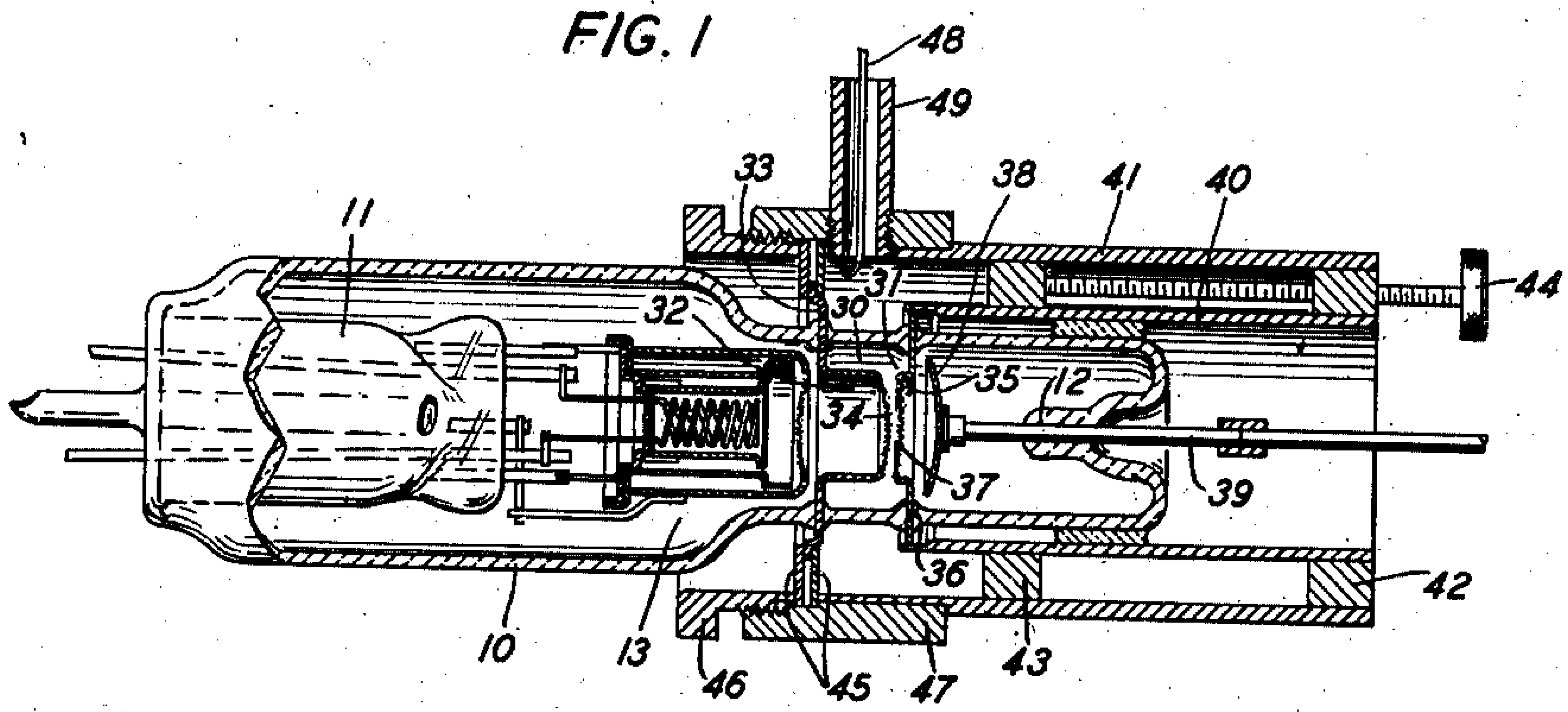
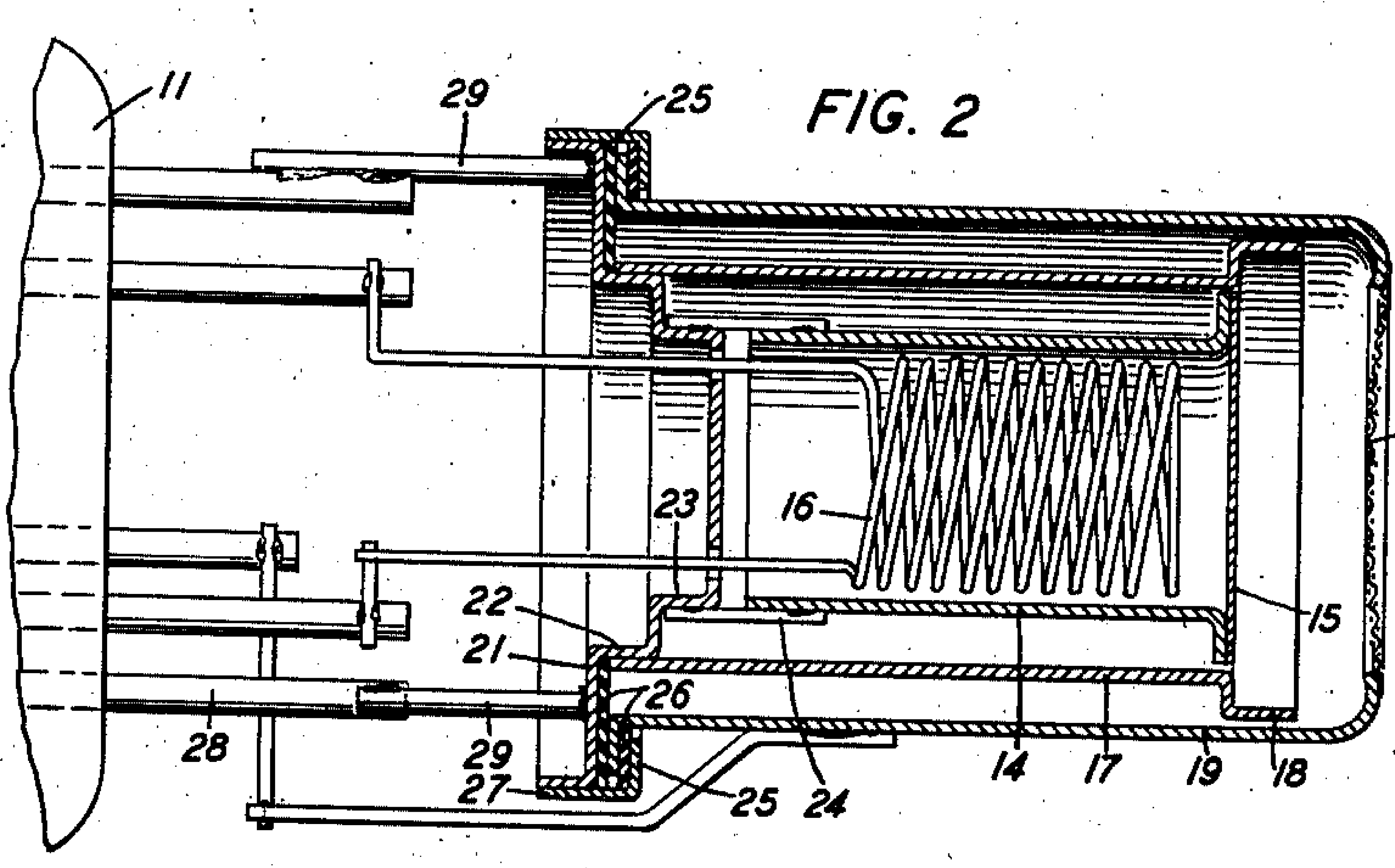


FIG. 2



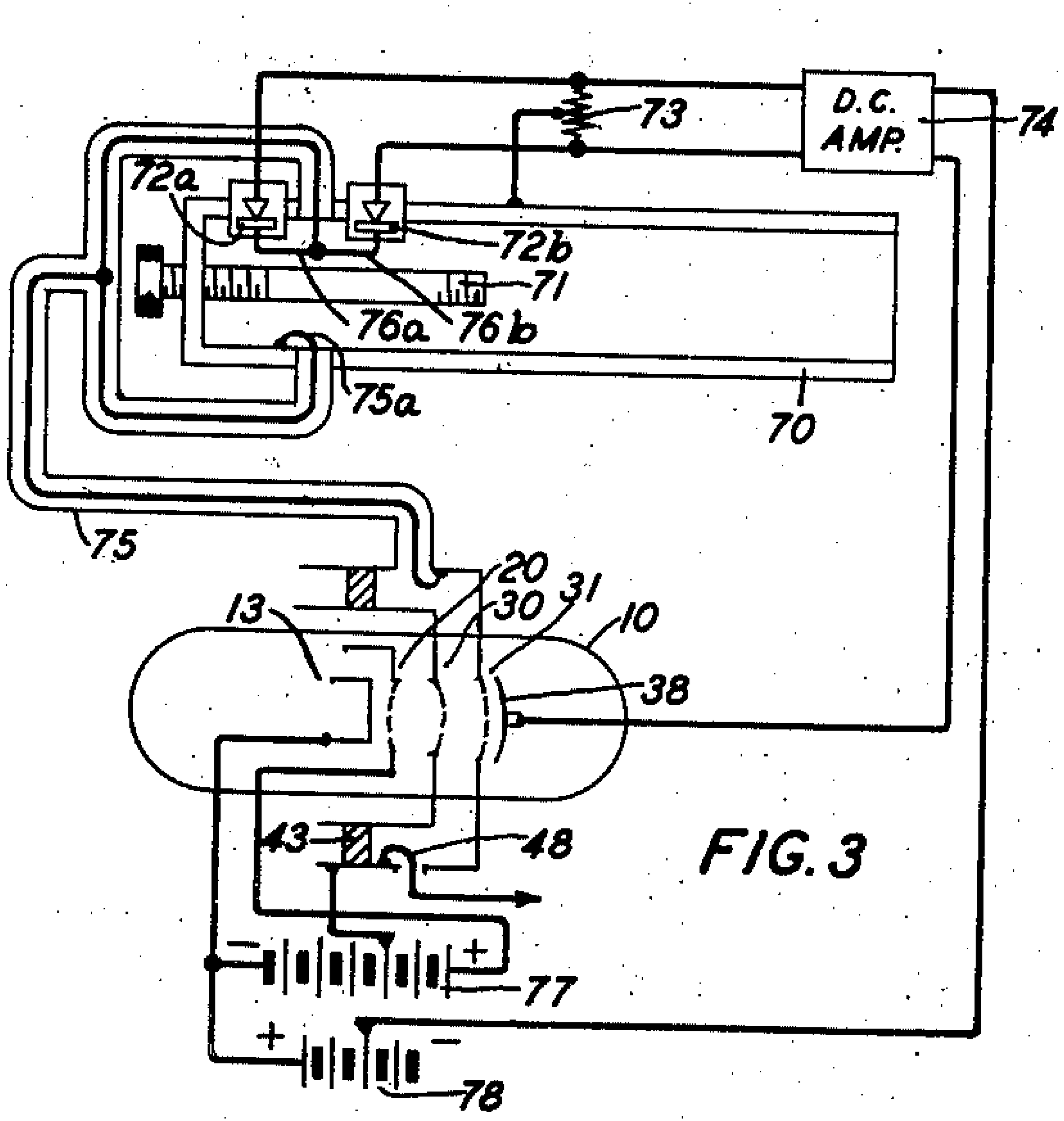
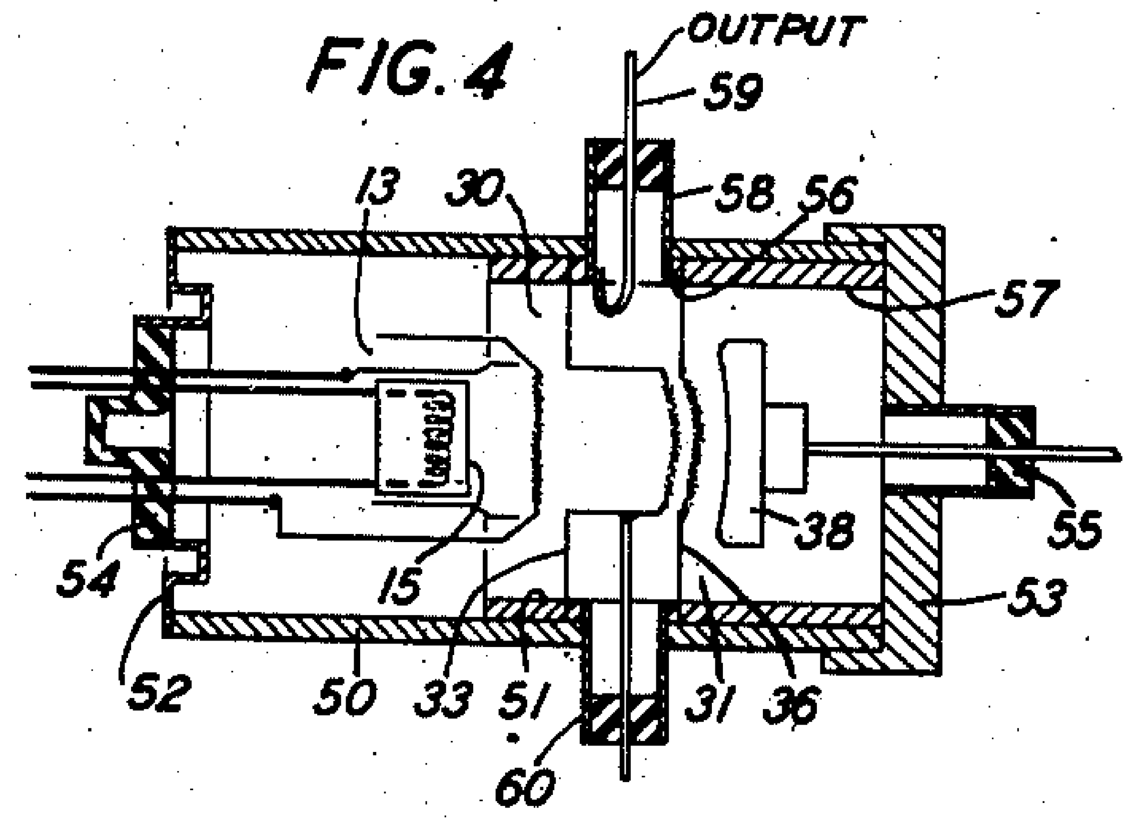


FIG. 3

FIG. 4



INVENTOR
J. R. PIERCE
BY
Walter C. Kiesel
ATTORNEY

Patented Sept. 3, 1946

2,406,850

UNITED STATES PATENT OFFICE

2,406,850

ELECTRON DISCHARGE APPARATUS

John R. Pierce, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 11, 1941, Serial No. 388,043

9 Claims. (Cl. 315—5)

1

This invention relates to electron discharge apparatus and more particularly to electronic ultra-high frequency oscillation generators.

One general object of this invention is to enable the facile and efficient generation of ultra-high frequency oscillations. More specific objects of this invention are to:

Enable the generation, electronically, of ultra-high frequency oscillations by apparatus requiring but relatively low voltages for operation;

Expedite the control and adjustment of ultra-high frequency electronic oscillation generators;

Simplify the construction of electron discharge apparatus and particularly of electron discharge devices adapted for use as generators of ultra-high frequency oscillations;

Improve the operating stability of electronic oscillation generators;

Reduce the radiation and other losses in ultra-high frequency oscillation generators and thereby to improve the efficiency thereof; and

Enable the generation of ultra-high frequency oscillation, within a fairly wide range of frequencies with a single electron discharge device.

In one illustrative embodiment of this invention, electron discharge apparatus comprises a space discharge device of the velocity variation type and including a pair of electrodes defining a gap and having cooperatively associated therewith conductive members constituting a resonant system with the electrodes, the device including also an electron gun for projecting an electron stream across the gap and an auxiliary electrode for affecting the electrons in the stream after they have crossed the gap and have been subjected to velocity variation thereat.

In accordance with one feature of this invention, the resonant system is utilized as both the input and output element of the apparatus. More specifically, in accordance with one feature of this invention, the electrodes of the electron discharge device are so constructed and arranged and are operated at such potentials that the electrons in the stream after traversing the gap and suffering a velocity variation are reflected in bunches and again projected across the gap in such manner as to deliver energy to the resonant system.

In accordance with another feature of this invention, the portions of the electrodes defining the velocity variation space, and the reflecting electrode are shaped and related so that substantially uniform electron transit times are realized in the space between the gap and the reflecting

2

electrode and a concentration of the reflected electrons is effected.

In accordance with a further feature of this invention, the resonant system is of the cavity resonator type and lies within the enclosing vessel of the electron discharge device, the cavity being bounded by the gap defining electrodes and a portion of the enclosing vessel of the device.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is a view mainly in section of an electron discharge device illustrative of one embodiment of this invention;

Fig. 2 is a view in section of the electron gun included in the device shown in Fig. 1;

Fig. 3 is a circuit diagram illustrating the use of the device shown in Fig. 1 as a constant frequency oscillator; and

Fig. 4 is a view in section of an electron discharge device illustrative of another embodiment of this invention.

Referring now to the drawing, the electron discharge device illustrated in Fig. 1 comprises an evacuated enclosing vessel 10, for example of vitreous material, having at opposite ends thereof inwardly extending aligned stems 11 and 12. Supported from the stem 11 is an electron gun designated generally as 13 which, as shown more clearly in Fig. 2, comprises a cathode including a cylindrical metallic shell 14 to one end of which there is secured a circular metallic member 15, the outer surface of which, i. e. the surface away from the stem 11, is coated with a material having good thermionic emission characteristics. The shell 14 encompasses a closely wound heater filament 16, for example of tungsten wire coated with an insulating material. The cathode is encompassed by a cylindrical beam forming electrode 17, which is coaxial with the cathode and has an end portion 18 of increased diameter extending from the plane of the periphery of the cathode member 15. The electron gun includes also an accelerating anode coaxial with the cathode and the beam forming electrode, the anode comprising a cylindrical portion 19 and a reticulated or grid end portion 20 dished or curved toward the cathode member 15 and concentric therewith.

The several electrodes constituting the electron gun are mounted and maintained in coaxial relation by a metallic foundation member 21 having a pair of cylindrical walls 22 and 23 about one, 22, of which the portion 17 of the beam forming electrode is fitted and to the other, 23, of which there are secured rigid, small diameter wires 24 affixed to the cathode shell 14. The cylindrical portion 19 of the accelerating anode is provided with a flange 25 extending between a pair of insulating washers 26, the anode being secured to the foundation member 21 by an annular clamping bracket 27 affixed to the member 21.

The electron gun, it will be noted, constitutes a unitary assembly which is supported from the stem 11 by a plurality of rigid wires 28 embedded in the stem, and to which wires the foundation member 21 is attached by rigid tie wires 29.

Mounted opposite the electron gun and coaxial therewith are a pair of electrodes, designated generally as 30 and 31, one, 30, of which includes a central cylindrical portion 32 integral with an annular disc 33 extending through the wall of the enclosing vessel 10 and hermetically sealed thereto, and includes also a dished reticulated or grid end portion 34. The other electrode, 31, includes a central cylindrical portion 35 integral with an annular disc 36 extending through and hermetically sealed to the wall of the enclosing vessel 10, and includes also a dished reticulated or grid end portion 37 conforming to and immediately adjacent the grid portion 34 of the electrode 30.

A dished circular reflecting electrode 38 is mounted opposite the electrode 31 and coaxial therewith and is supported from the stem 12 by a leading-in conductor 39.

Associated with the electrodes 30 and 31 and coaxial therewith are a pair of coaxial cylindrical conductors 40 and 41 which are joined at one end by an annular metallic spacer 42 and are slidably engaged intermediate their ends by an annular conductor 43 or plunger the position of which may be adjusted by a drive screw 44 secured thereto and threaded to the metallic spacer 42. The inner coaxial conductor 40 engages and may be secured to the annular disc portion 36 of the electrode 31. The outer coaxial conductor 41 is connected to the annular disc portion 33 of the electrode 30, as by way of metallic annuli 45 clamped to this disc portion and against the conductor 41 by clamping members 46 and 47 threaded to each other.

The electrodes 30 and 31 together with the coaxial conductors 40 and 41 define a resonant cavity which may be tuned to a desired frequency by adjusting the position of the plunger 43. Power may be taken from the cavity through a conductor 48 having a looped inner end as shown and extending through a cylindrical conductor 49 carried by the clamping member 47.

During operation of the device, the accelerating anode 19 is maintained at a positive potential with respect to the cathode and the reflecting electrode 38 is maintained at a negative potential with respect to the cathode. The electrodes 30 and 31 are maintained at the same positive potential with respect to the cathode. In one particular embodiment, operable in the 10 centimeter wave-length range, the accelerating anode 19 may be operated at the order of 330 volts positive, the electrodes 30 and 31 may be operated at the order of 250 volts positive, and the reflecting electrode 38 may be operated between 80 to 100 volts negative or between 22 to 32 volts negative, all with respect to the cathode.

The electrons emanating from the cathode 14, 15 are maintained in a substantially parallel beam by the beam forming electrode 17, 18 and are accelerated toward the gap between the grid portions 34 and 37 of the electrodes 30 and 31, respectively, due to the positive potential of the accelerating anode 19. In passing across the gap between the grid portions 34 and 37, the electrons receive a velocity variation and the velocity varied electron stream then passes into the space between the electrodes 31 and 38, wherein a bunching of the electrons occurs and the velocity variations are converted into density variations. Because of the negative potential upon the reflecting electrode 38, the bunched electrons are reversed in direction and again cross the gap between the grid portions 34 and 37 of the electrodes 30 and 31, respectively, traveling toward the cathode, and deliver energy to the resonant cavity. The device, therefore, is self-excited and operates to generate oscillations, which are of extremely low wave-lengths, for example, of the order of a few centimeters, depending upon the electrical parameters of the system.

The electrode 38 is so spaced with respect to the gap and is operated at such potential that the drift time, that is the total time an electron in the stream is in the space between the electrodes 31 and 38, considering both its motion from the gap toward the reflector electrode and in the reverse direction, is substantially equal to $(n-\frac{1}{4})$ cycles of the operating frequency, n being an integer, so that the returning electrons cross the gap in the proper phase to deliver energy to the resonant cavity. In practice, the resonant cavity is tuned to the desired operating frequency, by adjusting the position of the plunger 43, and the voltage upon the electrode 38 is then varied until the power output derived from the output loop 48 is a maximum.

The propriety of the requirement that the drift time for the condition of sustained oscillations shall be equal to $(n-\frac{1}{4})$ cycles of the operating frequency may readily be verified by considering the history of electrons crossing the gap at various phases of the electric field in the resonant cavity. For convenience, consider an electron (which will be referred to as the reference electron) that crosses the gap at the instant when the electric field is changing from the direction which produces electron acceleration to the direction which decelerates an electron. The speed of the reference electron is substantially the same upon leaving as upon entering the gap. The electron will travel a certain distance, d say, toward the reflector before being halted and will reach the gap again after traveling a total distance equal to $2d$. Such electrons as may have crossed the gap shortly ahead of the reference electron had their speed increased by the action of the electric field in the gap and hence penetrated further into the reflecting field than does the reference electron. Traveling a distance equal to more than $2d$, the speedier electrons will tend to return to the gap at substantially the same instant as the reference electron. Similarly, such electrons as may cross the gap shortly after the reference electron will be slowed down, will penetrate a smaller distance into the reflecting field, and, traveling a total distance equal to less than $2d$, will tend to return to the gap at substantially the same instant as those that started earlier. Thus it will be seen that the reference electron may be regarded as the center of an electron group. In order that the group may contribute energy to the electric field to offset the natural damping in the resonator, the group should return to the gap at an instant when the electric field is opposed to the motion of the electrons in the group and is of maximum intensity. Such an instant occurs substantially three-quarters of a cycle after the reference electron above described first crossed the gap and this and other such instants occur at the times determined by the value of $(n-\frac{1}{4})$ cycles of the operating frequency.

Some of the electrons traveling in the reverse direction, that is from the space between the electrodes **31** and **38** toward the gap between the grids **34** and **37**, will be collected by the electrodes **30** and **31**. However, a large percentage of the returning electrons will cross the gap, deliver energy to the resonant cavity and pass through the grid **34**, continuing thereafter toward the electron gun **13**. In the vicinity of or within the gun, such electrons will again have their direction of motion reversed and be directed back across the gap. These electrons thus again reversed in direction of motion have substantially random velocities and also are debunched, so that in again crossing the gap they deliver little energy to the resonant cavity. Effectively they intermingle with and act similarly to the electrons emanating from the cathode of the electron gun.

It has been found that this reflection effect and double reversal of the direction of motion of the electrons is augmented by the form of the grid portions **34** and **37** and of the electrode **38**, that is the dished form thereof, with the inner or concave surface thereof toward the electron gun and that thus shaping these elements reduces the magnitude of the current which must be drawn from the cathode to enable the attainment of a particular output power. The dished form of the electrodes, furthermore, results in uniform electron transit times in the region between the electrodes **31** and **38**.

It will be noted that in one sense the device shown and described is a velocity variation device wherein a single resonant cavity is utilized for both input and output. The transit time in the space between the gun and the electrode **30** is not critical. Furthermore, it will be appreciated that the device is susceptible of simple operation inasmuch as only one tuning adjustment and one potential adjustment, that of the electrode **38**, is necessary to effect variation of the operating frequency over a fairly wide range. For example, in the specific construction shown and described, oscillations over the range of 8 to 13.4 centimeters have been obtained and, operating with a second mode in the cavity, oscillations of 6 centimeters wave-length have been obtained. With the resonant cavity tuned to a particular frequency, the oscillator frequency may be varied by 20 to 30 megacycles by varying the potential of the electrode **38**.

It may be noted also that the coupling conductor **48** need not have any direct current connection to the cavity. Hence, the cavity need not be grounded and the device can be energized from a supply having a negative ground, such, for example, as the supply for an intermediate frequency amplifier. Also, it will be appreciated that but relatively low voltages, in comparison with the voltages employed in velocity variation devices of known construction, are necessary upon the electrodes of the device, this being due in part to the grid portions **34** and **37** utilized in the electrodes **30** and **31**.

The frequency of oscillation can be varied over a fairly wide range with but little resultant change in the output obtainable from the device, so that the device is suitable for use for frequency modulation purposes. For example, if the device were used for frequency modulation, an element would be inserted in the connection between the electrode **38** and the potential source therefor, for varying the potential of the electrode **38** in accordance with the signal to be modulated. As a specific illustration, such element could be the secondary winding of an output transformer the primary winding of which was in circuit with a transmitter or microphone.

Inasmuch as the frequency of oscillation is controllable by the potential of the electrode **38**, the device disclosed is particularly suitable for use as a beating oscillator with automatic tuning, in which case the electrode **38** would be appropriately associated with an automatic tuning circuit effective to maintain the potential of the electrode **38** at the value requisite for the generation of oscillations of the desired frequency to thereby maintain the correct relation between the beating oscillator and signal frequencies.

High frequency stability or, stated in another way, constant frequency operation of the device shown in Fig. 1, may be realized in one way illustrated in Fig. 3. In the circuit illustrated in this figure, the oscillator device **10** is associated with a high Q circuit, such as a resonant cavity defined by a cylindrical conductive member **70** the frequency of which cavity may be adjusted accurately by a screw **71**. Mounted adjacent one wall of the member **70** are a pair of identical rectifier elements **72a** and **72b** which are connected to opposite ends of a resistance **73** in turn connected across the input terminals of a direct current amplifier **74**, the mid-point of the resistance **73** being connected to the member **70**.

The resonant cavity of the device **10** is coupled to the resonant cavity **70** by a coaxial line **75** having a loop end **75a** within the cavity **70**, the line also connecting the first-mentioned cavity to two loops **76a** and **76b** in turn connected to the rectifier elements **72a** and **72b** respectively.

In operation, the accelerating anode **19** and the electrodes **30** and **31** have applied thereto appropriate positive potentials, as by battery **77**, as described heretofore in connection with Fig. 1, and the cavity of the device **10** and the potential of the electrode **38**, supplied by a battery **78**, are adjusted so that the device oscillates at the desired frequency. The resonant cavity **70** also is adjusted to this frequency.

When the discharge device **10** oscillates, energy is conveyed by the line **75** to the two loops **76a** and **76b**. Also, electromotive forces will be produced in these loops, opposite in phase as applied to the rectifier elements **72a** and **72b**, due to the currents induced in the cavity **70** by the loop **75a**. When the frequency of oscillations produced in the device **10** is the same as that to which the cavity **70** is tuned, the voltages produced at the rectifiers **72a** and **72b** by the line **75** directly and by the loop **75a** through the cavity **70** will be equal and substantially equal rectified voltages will be produced by the rectifier elements. Hence, substantially zero voltage exists across the resistance **73** and no voltage change occurs at the output terminals of the direct current amplifier **74**.

However, if the frequency of oscillations generated by the device **10** changes from that to which the cavity **70** is tuned, due for example to temperature effects in the discharge device or fluctuations in the voltages supplied to the electrodes thereof, the alternating current voltages appearing across the rectifier elements **72**a and **72**b will be unequal and consequently the rectified voltages will no longer balance so that a direct current voltage will appear across the input of the amplifier **74**. Hence, an amplified direct current voltage will be impressed across battery **78**, in such direction as to change the potential of the electrode **38** in the manner requisite to bring it to the value whereby the frequency of oscillations generated by the device **10** will be that to which the cavity **70** is tuned.

In the electron discharge device illustrated in Fig. 4, the enclosing vessel comprises a metallic cylinder **50** having an internal annular shoulder portion **51**, and metallic annular end portions **52** and **53** having sealed thereto insulating members **54** and **55**, respectively. Within the vessel are mounted an electron gun **13** and electrodes **30**, **31** and **38** which may be of the same general construction as the corresponding elements in the device shown in Fig. 1 and described hereinabove. The annular disc portion **33** of the electrode **30** is seated against one end of the internal annular portion **51** of the enclosing vessel and has bearing thereagainst a cylindrical metallic spacer **56** against which there is seated in turn the annular disc **36** of the electrode **31**. The electrodes **30** and **31** and the spacer **56** are fitted slidably within the cylinder **50** and may be clamped in position by a cylindrical sleeve **57** fitted within the metal cylinder **50**.

In this construction, the resonant cavity is entirely within the enclosing vessel, being defined by the electrodes **30** and **31**, the spacer **56** and the portions of the cylinder **50** between the discs **33** and **36**. Energy may be taken from the cavity through the conductor **59** which extends through an eyelet **58** secured to the cylinder **50** and is hermetically sealed to the eyelet by a glass or other insulating bead. The cavity may be tuned through a coaxial line **60** of adjustable effective length in shunt with the cavity, the inner conductor of the coaxial line being connected to the disc **33** and the outer conductor of the coaxial line contacting and being secured to the metal cylinder **50**.

The device illustrated in Fig. 4 may be operated in the same manner as the device shown in Figs. 1 and 2 as described heretofore.

A particular feature of the construction illustrated in Fig. 4 resides in the fact that the cavity does not include any joints so that power losses due to contact resistance losses in such joints or to radiation losses through gaps therein are avoided. Furthermore, the cavity is free from insulating material so that losses due to insulation in other constructions are avoided as are also extraneous capacities of such insulators. Also, it will be noted that this construction enables the very accurate alignment and spacing of the electrodes so that the construction of devices for operation at very high frequencies, at which accurate alignment and spacing of the electrodes is very important, is facilitated.

Although specific embodiments of the invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising a pair of spaced electrodes having juxtaposed reticulated portions defining a gap, an electron gun opposite one of said electrodes and in alignment with said gap, and a reflecting electrode opposite the other of said electrodes and in alignment with said gap, said reticulated portions being dished in the direction away from said electron gun.

2. Electron discharge apparatus in accordance with claim 1 wherein the face of said reflecting electrode toward said gap is dished in the direction away from said electron gun.

3. Electron discharge apparatus in accordance with claim 1 wherein said electron gun includes an accelerating electrode having a reticulated portion opposite said one electrode and dished in the opposite direction to the reticulated portion of said one electrode.

4. Electron discharge apparatus comprising a pair of coaxial electrodes having juxtaposed grid portions defining a gap, an electron gun opposite one of said electrodes and coaxial therewith, and a reflecting electrode opposite the other of said electrodes and in alignment with said gap, said grid portions being concavo-convex and uniformly spaced with the concave surface thereof toward said electron gun, and the surface of said reflecting electrode toward said other electrode being concave and uniformly spaced from the grid portion of said other electrode.

5. Electron discharge apparatus comprising an enclosing vessel having a cylindrical metallic portion provided with an internal annular shoulder, an electrode having an annular portion seated on said shoulder and having a central electron permeable portion, a second electrode having an outer annular portion and a central electron permeable portion in juxtaposition to said first electron permeable portion, a cylindrical metallic spacer member engaging said annular portions of said electrodes and bounding therewith a resonant cavity, an electron gun opposite one of said electron permeable portions, an auxiliary electrode opposite the other of said electron permeable portions, said annular portions and said spacer member being slidably fitted within said metallic portion of said vessel, and means securing said portions and spacer member against said shoulder.

6. Electron discharge apparatus in accordance with claim 5 comprising a variable coaxial line coupled to said cavity.

7. Electron discharge apparatus comprising an enclosing vessel having a cylindrical metallic portion, a pair of electrodes within said vessel and defining a resonant cavity with a section of said metallic portion, said electrodes having inner reticulated portions in juxtaposition and defining a gap and having also outer portions conductively connected to said metallic portion, an electron gun opposite one of said electrodes, and a reflecting electrode opposite the other of said electrodes, said reticulated portions being concavo-convex and having the concavo face thereof toward said electron gun.

8. Electron discharge apparatus in accordance with claim 7 wherein the surface of said reflecting electrode opposite said other electrode is coaxial with and curved in the same direction as the reticulated portion of said other electrode.

9. Electron discharge apparatus comprising a pair of electrodes having juxtaposed grid portions defining a gap, means cooperatively associated with said electrodes defining a resonant cavity therewith, an electron gun including a cathode opposite one of said grid portions, a re-

flecting electrode opposite the other of said grid portions, said grid portions being dished and having the inner faces thereof toward said electron gun, reflecting electrode having a dished surface facing the grid portion to which it is opposite, means for maintaining said pair of electrodes at a positive potential with respect to said cathode, and means for maintaining said reflecting electrode at a high negative potential relative to said cathode.

JOHN R. PIERCE.