July 9, 1957 H. V. NEHER 2,798,982

CONTROLLABLE OSCILLATOR TUBE

Filed Dec. 11, 1945 2 Sheets-Sheet 1

FIG. 1

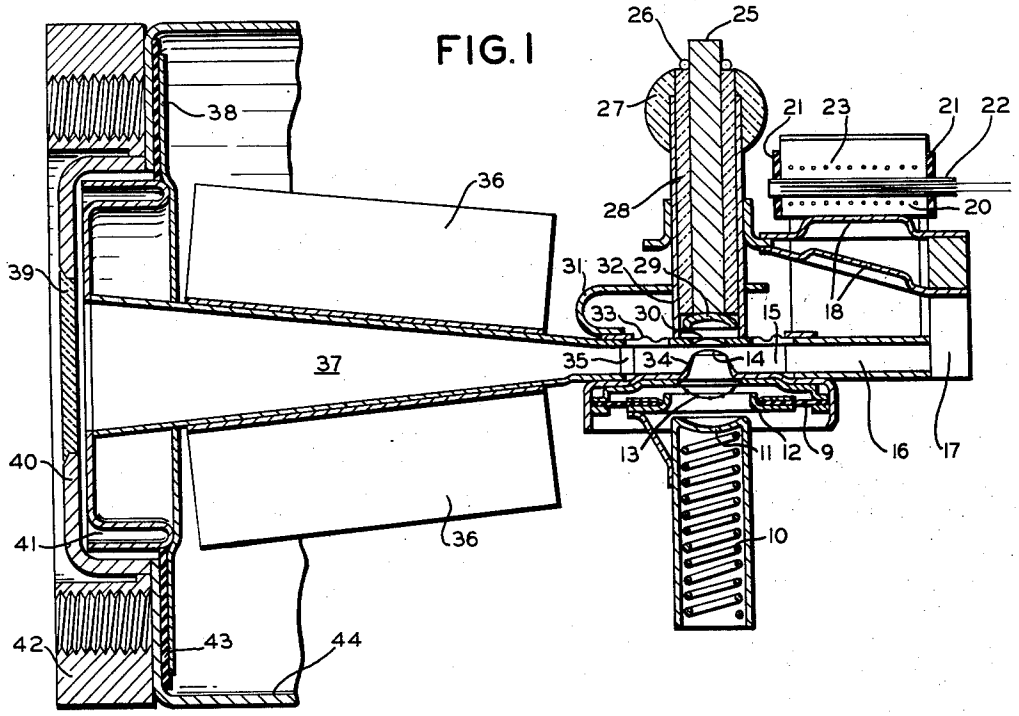

FIG. 2

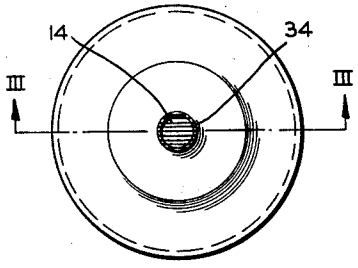

FIG. 3

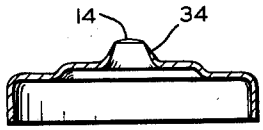

FIG. 4

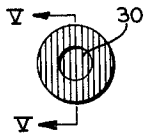

FIG. 5

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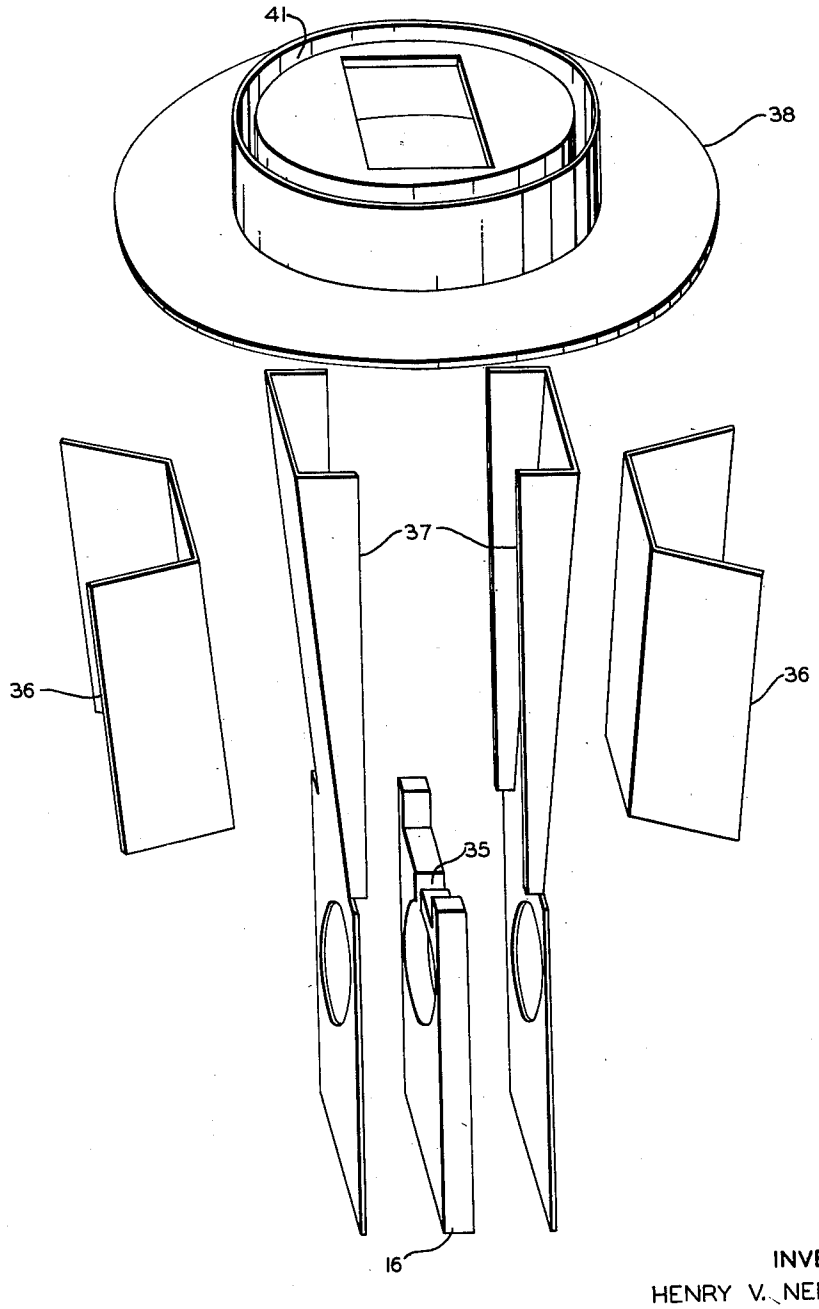
July 9, 1957 H. V. NEHER 2,798,982

CONTROLLABLE OSCILLATOR TUBE

Filed Dec. 11, 1945 2 Sheets-Sheet 2

FIG. 6



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CONTROLLABLE OSCILLATOR TUBE

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Application December 11, 1945, Serial No. 634,295

16 Claims. (Cl. 315—5.23)

This invention relates to an electron discharge device and more particularly, to a low-voltage velocity-modulated reflex type of oscillator incorporating grids. The output frequency of this oscillator, which is in and above the super high frequency (S. H. F.) band of the spectrum as defined and standardized by the Federal Communications Commission, is adjustable by means of an electrical circuit.

Conventional velocity-modulated reflex oscillators operating in and above the high frequency end of the S. H. F. band employ an electron gun, the emitted electron stream of which is caused to pass through small apertures placed along the axis of radial symmetry of the resonant cavity. It has been determined that for the condition of maximum power output the transit time of the electrons through the region of high field intensity surrounding the apertures should be approximately equal to one-half the natural period of the resonant cavity. Due to the tendency for the field to diverge if the size of the apertures is increased, either the apertures must be made small or the electron velocity must be increased to keep the transit angle approximately equal to 180 electrical degrees. Because of these factors, such velocity-modulated reflex oscillators require electrode operating potentials of 1800 to 2100 volts and have apertures which are not so small as to be difficult to manfacture uniformly.

Adjustment of the operating frequency over wide limits is usually accomplished by mechanically changing the physical spacing between the apertures in the resonant cavity of such an oscillator, while adjustment over narrow limits may be accomplished by variation of the negative potential difference of the reflector with respect to the cathode. The degree of frequency variation by the latter means is a direct function of the electrical losses involved in the frequency-determining impedance associated with the oscillator. Thus the operating frequency of an oscillator having low electrical losses in its resonant circuit cannot be varied over as wide a range by changing the reflector voltage as can that of an oscillator having high losses.

Coupling of the integral resonant circuit to a transmission line is usually accomplished by means of a single-turn inductor inserted into the electromagnetic field produced by the resonant circuit, the degree of coupling being a function of the position of the inductor relative to the field. The small physical dimensions of the coupling inductor and the resonant circuit require the maintenance of extremely small tolerances in assembly if oscillators having reasonably uniform characteristics are to be obtained.

Disadvantages inherent in conventional oscillators of the type described are the high operating potentials required, the lack of convenient electrical means for remotely changing the operating frequency over wide ranges, and the difficulty in obtaining an easily reproducible means for coupling the generated power to an external circuit.

It is an object of this invention to provide a velocity-modulated reflex type of oscillator capable of operating at super high frequencies and above which uses grids and does not require the use of excessively high operating potentials.

It is a further object of this invention to provide a velocity-modulated reflex type of oscillator, the output frequency of which is controllable over wide ranges by means of an electrical circuit.

It is a still further object of this invention to provide a velocity-modulated reflex type of oscillator in which a means is incorporated whereby the generated power is coupled to an external circuit in such a way that small manufacturing tolerances are not prerequisite to the production of oscillators having uniform output coupling characteristics.

These and other objects will be more apparent upon consideration of the following description together with the accompanying drawings, in which:

Fig. 1 is a sectional view of an embodiment of the invention;

Fig. 2 is a plan view of the second grid mounted on a truncated cone;

Fig. 3 is a sectional view along line III—III of Fig. 2;

Fig. 4 is a plan view of the third grid on its mounting ring;

Fig. 5 is a sectional view along line V—V of Fig. 4; and,

Fig. 6 is an exploded view of the waveguide assembly, cavity block and choke.

Specifically, with reference to the embodiment of this invention shown in Fig. 1, the oscillator comprises an electron gun consisting of a heater **10**, a cathode **11**, and a focussing electrode **12** designed to operate at the cathode potential. The electron gun assembly is mounted on a mica insulating support **9**. The first grid **13** is so positioned in the electron stream that it produces an additional focussing effect and helps to increase the uniformity of electron emission over the surface of the cathode.

The electron stream is caused to flow through apertures along the axis of radial symmetry of the resonant cavity **15**. A plurality of substantially parallel wires forming a grid is placed across each aperture so that the high-intensity field is confined largely within the space between the grids. The second grid **14** is mounted on the end of a truncated cone **34**, which forms the bottom of the resonant cavity, while the third grid **30** is mounted on a flat ring. The procedure for making the second grid **14** is as follows:

A one-half inch square sheet of 0.010 inch molybdenum with a 0.250 inch hole in the center is wound with 0.0006 inch diameter tungsten wire with a spacing of 0.0037 inch. A truncated cone **34**, as shown in Figs. 2 and 3, is formed from 0.005 inch thick low carbon content steel on which a 0.001 inch to 0.002 inch thick coating of copper is applied by electro-deposition. The copper-plated cone is placed on the grid winding in an inverted position, with the tip of the cone resting on the tungsten grid wires and with the one millimeter hole in the tip of the cone coaxial with the 0.250 inch hole in the molybdenum sheet. These parts are placed in an oven in this position and heated together in a hydrogen atmosphere until the copper begins to flow, imbedding the tungsten wires in the copper around the edges of the one millimeter hole in the tip of the cone. Heating is stopped when the copper starts to flow to prevent surface tension from pulling the copper away from the tip of the cone. The heated parts are allowed to cool until the copper solidifies and the cone is then separated from the molybdenum plate, breaking off the grid wires outside the periphery of the cone tip. The excess wires are then either broken off close to the cone tip with fine tweezers or removed with a fine abrasive stone. The grid wires are bowed outward

approximately 0.002 inch by inserting into the cone a rounded tool having a tip radius of 0.100 inch.

It is desirable that the cone be fabricated from a steel having a low carbon content, such as Swedish iron, since the tungsten wires carbonize during heating and become extremely brittle when higher carbon content steel is used.

The third grid **30**, shown in Figs. 4 and 5, is made as follows:

A sheet of molybdenum 0.005 inch thick is pierced with a number of 0.046 inch diameter holes and is then given a 0.0005 inch coating of gold by electro-deposition. Two such sheets of gold-plated molybdenum are then clamped together with a third sheet, which has been coated with a ceramic or other material to which gold will not adhere, placed between them. The three sheets, forming a laminated unit, are then wound with tungsten wire having substantially the same diameter and spacing as that used in forming the second grid and are placed in an oven and heated in a hydrogen atmosphere until the gold fuses, causing the tungsten wires to be gold-soldered to the molybdenum sheets. The laminations are separated with a razor blade and disks concentric with the 0.046 inch diameter holes are cut with a blanking die. In this manner, a large number of grids with mounting rings can be fabricated with but one winding and heating operation. The grids **30** so formed are bowed by means of a rounded tool to conform with the profile of the second grid **14**. Distortion of the grid wires in this manner insures that when they expand due to heating, the wires of both the first and second grids will move in the same predetermined direction and by the same amount, thus maintaining a constant separation between the grids.

The performance of the oscillator depends critically upon the position and shape of the reflector **29**. The tilt of the axis of the reflector must be maintained accurately to within one degree to prevent the phase variation of the reflected electrons from exceeding 90 electrical degrees. This precise alignment is accomplished by enclosing the reflector in a steel cylinder **32** and supporting it coaxially with a ceramic tube **28**, which provides electrical insulation. The steel alignment cylinder is given a coating of silver and copper in approximately eutectic proportions by electro-deposition.

A ring of nickel wire **26** is spot-welded to the reflector conductor **25** which passes through the ceramic tube **28** to fix the reflector **29** in the ceramic tube. The proper position of the reflector **29** with respect to the third grid **30** is maintained by means of ceramic cement **27**.

A 0.005 inch thick circular diaphragm **33** of a copper-plated alloy having a low coefficient of thermal expansion, such as Kovar, and having concentric corrugations to provide axial flexibility, forms the top of the resonant cavity **15**. The mounting ring containing the third grid **30**, the silver-copper-plated reflector alignment cylinder **32** and the copper-plated Kovar diaphragm **33** are placed in a jig which holds the parts coaxial and spot-welded together. The assembly is then placed in an oven and heated until the silver and copper plating, forming a solder, flows into the cracks and forms a fillet between the diaphragm and the grid ring.

The resonant cavity **15** is formed by a 0.230 inch diameter hole in a block **16** of copper-plated steel 0.040 inch thick, closed on one end by the cone **34** holding the second grid **14** and on the other by the diaphragm **33** and the third grid **30**. One side of the cavity is cut away, as shown in Fig. 6, thus forming an impedance matching transformer **35** between the resonant cavity, and the tapered waveguide transmission line **37**. The dimensions of the impedance matching transformer **35**, which is 0.020 inch long, 0.040 inch high and 0.095 inch wide, are so selected that a satisfactory compromise is effected between degree of coupling and the variation of impedance as a function of frequency.

Two sheets of copper-plated steel, each bent to form a tapered U-shaped channel as shown in Fig. 6, are fastened to the flat surfaces of the cavity block. One such sheet is held between the cavity block **16** and the diaphragm **33** holding the third grid **30**, while the other is mounted between the cavity block and the cone **34** holding the second grid **14**. The sheets are spot-welded and silver-soldered together so as to form a waveguide transmission line **37** in the form of a tube having a rectangular cross section tapering from inside dimensions of 0.040 inch by 0.410 inch to 0.170 inch by 0.410 inch. Cooling fins **36**, formed from 0.005 inch thick copper sheet, are fastened to the tapered waveguide transmission line as shown in Fig. 1 and Fig. 6 to aid in dissipating the heat produced in the oscillator. A choke **41** having a circular slot 90 electrical degrees deep and with the bottom of the slot placed 180 electrical degrees from the center of the wide edge of the waveguide is fastened to the large end of the tapered waveguide transmission line **37**.

The choke is electrically insulated from and is held in position coaxial with a sheet steel envelope **44**, which is preferably evacuated and encloses the complete apparatus shown in Fig. 1, by means of a mica ring **43**, placed between the envelope and a skirt **38** fastened to the choke. Power is extracted from the evacuated envelope through a 0.250 inch diameter window **39** of low-loss glass having a definite thickness and being sealed into a cup **40** of metal having the same thermal coefficient as the low-loss glass, such as Kovar. The proper thickness of the glass window is a function of the dielectric constant of the glass at the operating frequency and may be so selected that the overall reflection coefficient of the glass window in combination with the choke is very low, resulting in a voltage standing-wave ratio of approximately 1.1 to 1.

A metal collar **42** is fastened to the top structure of the envelope to provide means for fastening the tube to the external transmission line fittings.

Tuning of the resonant cavity **15** is accomplished by varying the spacing between the second grid **14** and the third grid **30**. A V-shaped tuning strut **18**, consisting of two Nichrome strips 0.005 inch thick and 0.110 inch wide with the central portion stiffened by an embossed ridge, is fastened to the cavity block by means of a yoke **17**. The vertex of the strut is fastened to the reflector alignment tube **32**. The upper member of the strut **18** forms the anode of a triode electron tube **20** having a grid **23** and an indirectly heated cathode **22** held in position by mica supports **21**. A decrease in the negative potential difference between the grid **23** and the cathode **22** causes an increase in space current. The resulting increase of electron bombardment of the anode causes it to heat and expand. The differential expansion thus produced between the two members of the strut causes the reflector alignment cylinder **32** to move toward the cathode **11**. The spacing between the second and third grids, **14** and **30** respectively therefore decreases, causing a decrease in the frequency of the oscillations. A 0.003 inch thick by 0.100 inch wide copper strip **31** is fastened between the reflector alignment cylinder **32** and the cavity block **16** to conduct the heat away from the ends of the struts **18** and to conduct away the heat caused by intercepted current flowing in the third grid **30**.

The entire inner structure is coated with a colloidal suspension of carbon in water after assembly to increase the heat dissipation properties of the oscillator. The inside of the metal envelope **44** is blackened by oxidation before assembly of the oscillator.

An alternative method of construction, resulting in somewhat better operating characteristics, involves the fastening of the inner structure to the envelope by a metal block to permit adequate heat dissipation, and eliminating the blackening process. This is a disadvantage from the operational standpoint because the envelope must be operated at a potential difference with respect to ground.

In this case, the metal collar 42 is replaced by one composed of an insulating material such as a phenolic resin, thus facilitating mechanical connection to the external transmission line although maintaining electrical insulation.

The oscillator herein described operates with a potential difference of 300 volts between the cathode and the resonant cavity structure and with a reflector potential of less than 150 volts negative with respect to the cathode. The oscillator is tunable over a 6 percent band of frequencies by means of any suitable electrical circuit controlling the potential difference between the grid and cathode of the triode 20, the tuning being accomplished in approximately 1.2 seconds.

Since certain changes may be made in the above described article and different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense, and particularly, that dimensions of parts herein described be regarded as illustrative only and therefore, that the invention is to be limited only by the prior art and the spirit of the appended claims.

What is claimed is:

1. An electron discharge device comprising an evacuated envelope, a cathode capable of emitting electrons, a focussing electrode for said electrons, a first grid of wires spaced from said focussing electrode and cooperating therewith to form said electrons into an electron stream, a cavity resonator having said first and additional second and third grids so positioned that said electron stream is passed through said grids, a reflector so positioned as to return said electron stream toward said cavity resonator, an opening in said cavity resonator forming an impedance-matching transformer, a waveguide transmission line having one end electrically connected to said impedance-matching transformer and the other end open, a choke surrounding the periphery of said open end of said waveguide transmission line, and a tuning strut including members so positioned that linear expansion of one of said members changes the spacing between said second and third grids in said cavity resonator.

2. The combination of claim 1 with another electron discharge device including a cathode, grid, and anode, said anode being formed by one of said strut members, the current flow between said cathode and said anode being controlled by said grid to control thereby the temperature and thermal expansion of said one member and hence the resonant frequency of said cavity resonator.

3. In an ultra-high frequency reflex velocity-modulated tube oscillator, the combination of an evacuated envelope containing a cavity resonator having parallel apertures, a fine wire grid, a cone shaped frame having an aperture, means mounting said grid and said frame across said aperture to form a re-entrant base for said cavity resonator, a flared wave guide coupled to said cavity resonator within said evacuated envelope for transmitting the power generated by said oscillator to an external load, and means associated with said cavity resonator for controlling the spacing of said apertures of said cavity resonator for controlling the frequency of said oscillator.

4. In an ultra-high frequency reflex velocity-modulated tube oscillator, an evacuated envelope, tuning apparatus within the evacuated envelope comprising a cavity resonator having parallel apertures, fine wire grids adapted to be mounted across said apertures, an opening in said cavity resonator forming an impedance-matching transformer, a flared wave guide transmission line coupled to said impedance-matching transformer for transmitting the power generated by said oscillator to an external load, strut means coupled to said cavity for changing the spacing of said apertures in accordance with temperature variations in said strut means, and means coupled to said strut means for controlling the temperature of said strut means to control the frequency of said oscillator.

5. An electron discharge device comprising an enclosing vessel, a unitary mount assembly within said vessel including a foundation plate having an aperture therein, a flexible diaphragm assembly having a grid portion, extending over one end of said aperture, a grid assembly extending over the other end of said aperture, having a grid in alignment with said grid portion, and defining a cavity resonator with said diaphragm assembly and the bounding wall of said aperture, an accelerating grid in alignment with said grid portion, a frame mounting said accelerating grid and affixed to said grid assembly, a cathode and auxiliary electrode mounted from said frame and defining an electron gun with said accelerating grid and an electronic unit for tuning said resonator mounted from said foundation plate, and means supporting said assembly within said vessel.

6. An electron discharge device comprising means defining a cavity resonator, said means including a plate having an aperture therein, a first metallic member having a grid, secured to said plate and extending across one end of said aperture and a second metallic member having a grid, affixed to said plate and extending across the other end of said aperture, an electron gun opposite said second member, a sleeve member affixed to and extending from said first metallic member, a repeller electrode within said sleeve member, and means locating said repeller electrode within said sleeve member.

7. An electron discharge device comprising, an enclosing vessel having a base, a unitary assembly within said vessel comprising a foundation member having an aperture therein, means mounted by said member and defining a cavity resonator with the bounding wall of said aperture, electrode means opposite said aperture, supported from said member and defining an oscillator unit with said resonator, and rigid support means affixed to said assembly and to an inner wall portion of said vessel removed from said base.

8. An electron discharge device comprising, a plate having an aperture therein, means including a flexible member at one end of said aperture, defining a cavity resonator with a bounding wall of said aperture, electrode means thereadjacent for energizing said resonator, a support affixed to said plate and having an arm, a drive member coupled to said flexible member for actuating it, strut means supported from said arm and coupled to said drive member for displacing the latter to flex said flexible member, thereby to tune said resonator, in accordance with temperature variations in said strut means, and means for controllably heating said strut means comprising electrode means.

9. An electron discharge device comprising, means defining a cavity resonator, said means including a plate having an opening extending between opposite faces thereof, a first member affixed to one face of said plate, extending across one end of said opening and having a grid portion axially aligned with said opening and a second member affixed to the opposed face of said plate, extending across the other end of said opening and having a grid portion axially aligned with said first grid portion, a cylindrical sleeve extending from said first member and axially aligned with said first grid portion, a repeller electrode within said sleeve, means fitted within said sleeve and positioning said repeller electrode in coaxial relation with said first grid portion, and an electron gun opposite said second grid portion.

10. An electron discharge device in accordance with claim 9 comprising a support mounted from said opposite face of said plate and having a cylindrical portion coaxial with said second grid portion and wherein said gun includes a cathode having an emissive face opposite said second grid portion, and an auxiliary electrode coaxial with said emissive face, the device comprising also an annular member fitted coaxially within said cylindrical por-

tion and mounting said cathode and said auxiliary electrode.

11. An electron discharge device comprising an evacuated envelope containing a reflex velocity modulated oscillator having a cavity resonator, a wave guide mounted within said envelope and communicating with the interior of said cavity resonator for coupling the power generated by said oscillator to a load external to said envelope, and means attached to said cavity resonator for altering the configuration of said cavity resonator to control the frequency of said oscillator.

12. In combination, an evacuated envelope containing a reflex velocity modulated oscillator having as a component thereof a cylindrical cavity resonator with grid structures disposed in a pair of apertures in the opposite parallel end walls of said cavity resonator, said envelope having a window transparent to the propagation of the electromagnetic energy generated by said oscillator, a tapered wave guide coupling the power generated by said oscillator to said window, and electronic means attached to said cavity resonator for changing the separation between said grid structures whereby the resonant frequency of oscillation of said cavity resonator is varied.

13. In combination, an evacuated envelope containing a reflex velocity modulated high frequency oscillator having as a component thereof a cylindrical cavity resonator which has first and second grids disposed in apertures in the opposite parallel end walls thereof, said envelope having a window that is transparent to the propagation of electromagnetic energy, a tapered wave guide section, the flared end of said wave guide section confronting said window and the throat of said wave guide communicating with the interior of said cavity resonator whereby electromagnetic energy generated by said oscillator is transmitted via said wave guide section and said transparent window to an external load and an electronically heated tuning structure attached to said cavity resonator for varying the spacing between said first and second grid structures and thereby the resonant frequency of said cavity resonator.

14. In an automatic frequency tuning arrangement for use with a high frequency, velocity modulated reflex oscillator having first and second grid structures disposed in apertures in the opposite parallel end walls of a cavity resonator, means for regulating the spacing between said grid structures and thereby the resonant frequency of oscillation of said cavity resonator comprising, a flexible diaphragm securing a first one of said grid structures to its adjacent end wall, a repeller electrode, said electrode being mounted within a cylindrical tube member one end of which is secured to said flexible diaphragm, whereby said electrode is maintained in spaced coaxial alignment with said first grid structure, a V-shaped tuning strut, the apex of said strut being attached to said cylindrical tube member and its base being fixed to said cavity resonator,

one leg of said V-shaped strut forming the anode of an electron tube whereby upon electron bombardment of said anode said strut is deformed to cause said first grid and said repeller electrode to move together as a unit to or away from said second grid structure.

15. In an automatic frequency tuning arrangement for use with a high frequency, velocity modulated reflex oscillator having first and second grid structures mounted in relatively small apertures in the opposite parallel end walls of a re-entrant cavity resonator, means for regulating the separation between said grid structures comprising, a flexible diaphragm securing a first one of said grids to its adjacent end wall, a repeller electrode, means for maintaining said electrode in coaxial alignment with said first grid structure a predetermined distance therefrom, said means including a cylindrical tube member having one of its ends secured to said diaphragm, a yoke projecting from said cavity resonator, a V-shaped tuning strut having its apex attached to said cylindrical tube member and its base attached to said yoke, and means for bombarding one leg of said strut with an electron stream of variable density so as to heat unequally the leg members of said strut and thereby cause its deformation, whereby said first one of said grids and said repeller electrode are both deflected with respect to the second one of said grids.

16. In an automatic frequency tuning arrangement for use with a high frequency, velocity modulated reflex oscillator having first and second grids mounted in a pair of apertures in the opposite parallel end walls of a cylindrical cavity resonator, means for regulating the separation between said grids comprising, a flexible diaphragm securing a first one of said grids to its adjacent end wall, a tubular member supported from said diaphragm, a repeller electrode mounted within said tubular member so as to be maintained in coaxial alignment with the first one of said grids a fixed distance apart, a V-shaped tuning strut, the apex of said strut being secured to a wall portion of said tubular member and the base of said strut being secured to said cavity resonator, one leg of said strut forming the anode of an electron tube, an evacuated envelope, said envelope having a window transparent to the propagation of electromagnetic energy, said cavity resonator being disposed within said evacuated envelope, and a tapered wave guide section having its flared end confronting said window and its throat end coupled to an opening cut in the side wall of said cavity resonator.

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