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2,589,739

ELECTRICAL OSCILLATOR HAVING OPEN-ENDED COAXIAL RESONATOR

Filed Aug. 27, 1947

3 Sheets-Sheet 1

FIG. 1.

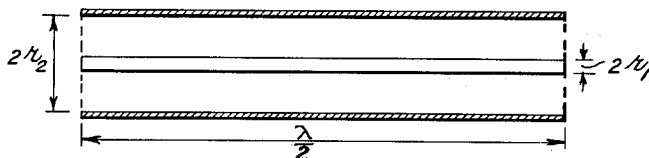


FIG. 2.

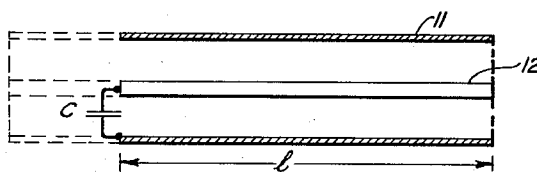


FIG. 3.

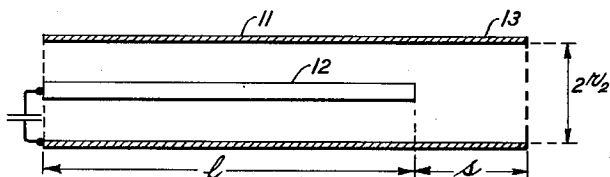
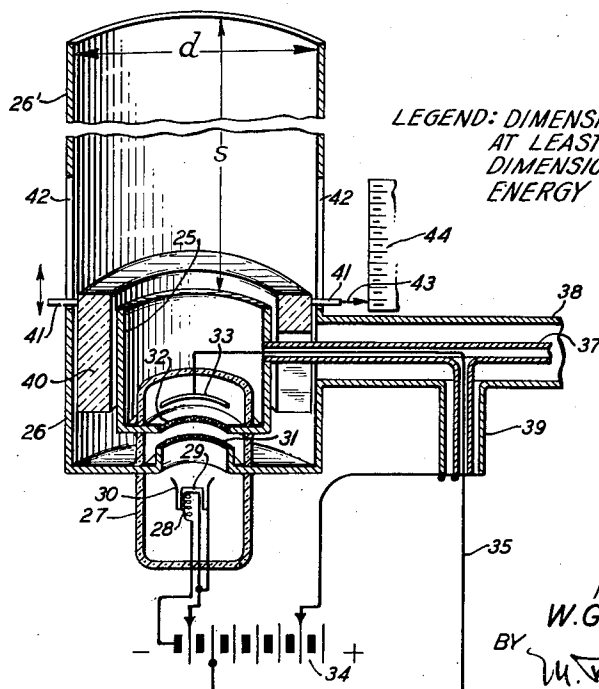


FIG. 4.



LEGEND: DIMENSION S SHOULD BE
AT LEAST 2 TO 3 TIMES
DIMENSION d FOR LOW
ENERGY LOSS AT OPEN END

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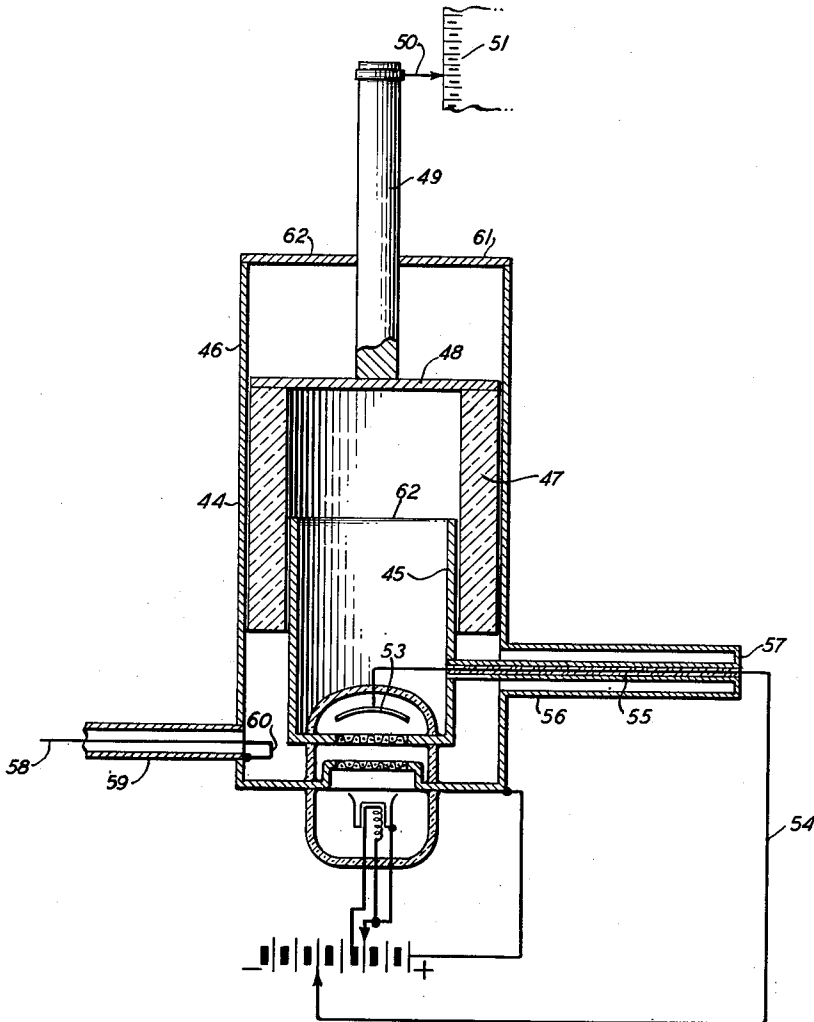
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FIG. 5.



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FIG. 6.

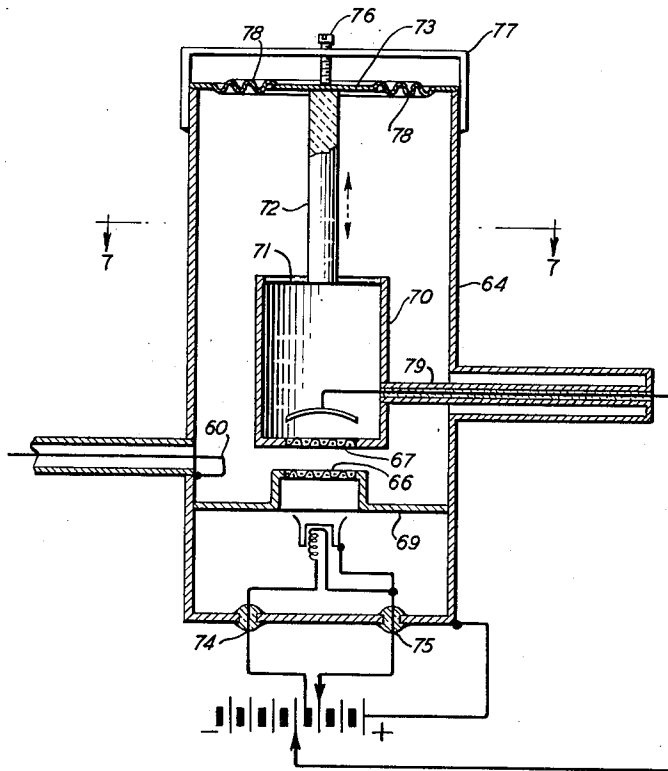


FIG. 7.

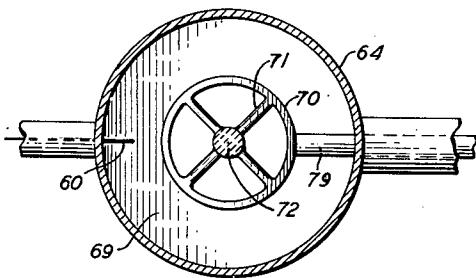
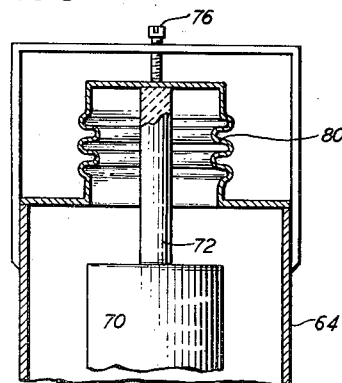


FIG. 8



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ELECTRICAL OSCILLATOR HAVING OPEN-ENDED COAXIAL RESONATOR

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5 Claims. (Cl. 250—36)

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This invention relates to microwave resonators and more particularly to the application of such resonators as frequency-determining components of microwave oscillators.

An object of the invention is to increase the size of the physical structure of a microwave resonator.

Another object of the invention is to enable the use of resonators of conveniently large physical dimensions as the frequency-determining components of microwave electrical oscillators.

An additional object of the invention is to facilitate the use of reflex type oscillators at high microwave frequencies.

A very useful type of microwave oscillator is the so-called reflex oscillator disclosed by J. R. Pierce at page 112 of the Proceedings of the I. R. E. for February 1945, volume 35, No. 2. As the frequency of such oscillators is increased it becomes increasingly difficult physically to construct the necessary resonant circuits. An attempt has been made to overcome this difficulty by employing an harmonic mode of oscillation of a relatively large cavity resonator which has a fundamental mode of resonance of considerably lower frequency than that of the desired oscillations. However, with reflex oscillators having such larger frequency-determining resonators another difficulty is encountered in that oscillators of the reflex type tend to oscillate at the gravest or most fundamental mode of the resonator. This tends to make operation at the desired higher frequency unstable.

In accordance with the invention a high Q resonator is constructed as a coaxial structure of a half wavelength with both ends electrically open. In order to sustain oscillations in the resonator there may be coupled to it an electron tube of the reflex type the coupling preferably being effected by interaction of the electron stream and the electromagnetic field of the resonator at an interaction gap in the tube. The reflex tube may be so designed as to maintain its internal capacitances relatively low. Coupling of the interaction gap of the tube to the resonator adds a capacitive loading thereto thus requiring that the resonator be somewhat physically shortened to compensate for the capacitive loading. However, the resultant resonant structure will still be substantially a quarter wavelength longer than would a quarter wavelength structure short-circuited at one terminal.

There is a tendency for the coaxial resonator to radiate energy from the high impedance electrically open terminal remote from the electron

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interaction space. To preclude this the outer cylindrical member of the coaxial resonator is extended beyond the inner conductor to constitute a tubular wave guide. Moreover the diameter of the tubular wave guide is so predetermined that the guide has a low frequency cut-off at a frequency substantially above that of the oscillations corresponding to the natural resonance frequency of the coaxial section. Under these circumstances energy of the desired oscillation frequency may not escape from the resonator through the tubular wave guide.

The basic oscillation frequency is primarily determined by the electrical dimensions of the resonator as modified by the associated electron discharge device. A lesser effect in frequency determination is exercised by the transit time of the electrons in their course in the retarding field. Variation of the frequency may be effected by a dielectric tuner movable into the space between the coaxial conductors of the resonator section to vary the natural resonance frequency of the coaxial resonator.

In the drawing:

Fig. 1 shows schematically a half wavelength coaxial resonator open electrically at each end;

Fig. 2 indicates the diminution in length required when a loading capacitance is connected across the structure near one end;

Fig. 3 shows an extension of the outer tubular member of Fig. 2 to provide a wave guide;

Fig. 4 is a schematic structural and circuit diagram of an embodiment of the invention in a reflex oscillator;

Fig. 5 illustrates a modification of the oscillator of Fig. 4;

Fig. 6 illustrates schematically a modification employing a metallic container;

Fig. 7 is a section along line 7—7 of Fig. 6 viewed in the direction of the arrows; and

Fig. 8 shows a modification of the structure of Fig. 6.

Fig. 1 presents schematically a half wavelength resonator open-circuited at both ends. Such a resonator is twice as long as the customary quarter wavelength resonator short-circuited at one end. It therefore tends toward a final structure of considerably larger dimensions than the quarter wavelength resonator and this increase in structural dimension is particularly advantageous when dealing with microwave oscillations of high frequencies and under circumstances where it is necessary to couple the resonator with an electron discharge tube.

Fig. 2 indicates the effect upon the structure

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of Fig. 1 when it becomes necessary to load the resonator with a capacitance C such as that between the electrodes of a coupled electron discharge tube. In order to maintain the resonance frequency at its original value it is necessary to compensate for the loading capacitance by decreasing the physical length of the resonator to a dimension γ somewhat less than $\lambda/2$ but still very much greater than $\lambda/4$.

Fig. 3 illustrates diagrammatically the modification of the structure of Fig. 2 by extending the outer coaxial conductor 11 beyond the inner coaxial conductor 12 by a dimension s at the same time giving the extended portion 13 such a diametral dimension as will cause the extended portion acting as a wave guide to present a transmission characteristic of the high pass-band filter type such as to prevent escape there-through from the open end of the coaxial resonator 11, 12 of oscillation energy of the natural resonance frequency of that resonator.

Assuming in Fig. 1 a coaxial transmission line with ideal open circuits at each end the wavelength measured along the coaxial structure is determined by the equation

$$\lambda = \frac{c_1}{f} = \sqrt{\epsilon} 2l_0 \quad (1)$$

where

λ is the wavelength in the coaxial
 C_1 is the wave propagation velocity in the coaxial
 γ_0 is the physical length of the coaxial section,
 and

ϵ is the dielectric constant of the dielectric medium between the inner and outer conductors.
 Hence

$$\frac{\lambda}{4} = \frac{l_0 \sqrt{\epsilon}}{2} \quad (2)$$

If r_1 and r_2 are respectively the inner and outer radii of the coaxial conductors, r_1 being measured as an external dimension and r_2 as an internal dimension, and if one is to insure that only the fundamental mode of oscillation is to occur

$$r_1 + r_2 < \frac{1}{\pi} \frac{c_1}{\sqrt{\epsilon} f} \quad (3)$$

In the case of Fig. 2, the length dimension γ_0 of the resonator of Fig. 1 must be changed to some shorter dimension γ to compensate for the loading effect of the capacitance C which will be a function of the design and electrical dimensions of the coupled electronic device.

Assuming that the coaxial resonator has been so designed as to compensate for the coupled tube there remains the problem of excessive energy radiation from the electrically open end of the resonator remote from the electron tube. Fig. 3 presents the solution of this problem by an extension 13 of the outer tubular coaxial member for a distance s thus constituting a hollow tube wave guide extending beyond the inner coaxial member 12. The cut-off of the hollow tubular wave guide may be determined by

$$\lambda_c = \sqrt{\epsilon} \frac{2\pi a}{1.841} \quad (4)$$

where λ_c is a desired cut-off wavelength shorter than the wavelength of the dominant mode of oscillation for the open-ended coaxial resonator, ϵ is the dielectric constant of the dielectric medium within the wave guide, and $a=r_2$ the radius of the wave guide section.

Equation 4 and the following equations are

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based on the condition in which the space between the coaxial conductors contains no dielectric material. They may be assumed to apply also where the amount of the dielectric material is small so that its effect may be neglected. Where substantial amounts of dielectric material are employed allowance must be made for the dielectric material and each configuration requires a special design. The principles involved, however, remain the same. The presence of a solid dielectric in the cut-off wave guide makes it necessary to reduce the diameter of the wave guide to insure cut-off at a predetermined cut-off frequency. For this reason it is advantageous not to have any solid dielectric tuner of greater length than is necessary.

The attenuation x of a cut-off circular guide in decibels per unit length at any frequency f corresponding to a wavelength λ is

$$x = \frac{54.6}{\lambda c} \left[1 - \left(\frac{\lambda c}{\lambda} \right)^2 \right]^{1/2} \text{ db/unit length}$$

For the dominant mode

$$\lambda_c = \frac{\pi d}{1.841} \quad (5)$$

where $d=2a=2r_2$.

Assuming in an illustrative example

$$\lambda_c = .86\lambda$$

$$x = \frac{28 \times 1.841}{\pi d} \text{ db/unit length} \quad (7)$$

with a ratio

$$n = \frac{s}{d} = \frac{s}{2r_2} \quad (8)$$

$$x = 16.4 n \text{ db}$$

To realize a high Q it is necessary that the energy at the dominant mode leaking out of the circular guide must be low. It should therefore experience an attenuation of the order of 30 to 40 decibels. We may conclude from (8) that with the assumption

$$\frac{\lambda_c}{\lambda} = .86$$

n should have a minimum value of 2 to 3.

Fig. 4 illustrates the application of the open end resonator to a reflex type oscillator. The coaxial resonator consists of an inner tubular conductor 25 and an outer tubular conductor 26. These coaxial conductors are supported at their lower ends by the dielectric envelope of a discharge device 27 of the repeller type having a cathode heater 28, cathode 29, beam electrode 30, grids 31 and 32 and a repeller electrode 33. The grids 31 and 32 are centrally aligned with the coaxial conductors 26 and 25 respectively. When the cathode is energized in the usual manner and the grids 31 and 32 are polarized to a high positive potential by the source 34, the electron gun constituted by the cathode beam electrode and grid 31 will impel a beam of electrons through the grids 31 and 32 toward the repeller 33. With the repeller 33 polarized over the conductor 35 to a negative potential with reference to the cathode, the device will operate as described in the Pierce article to which reference has been made to produce oscillations of a frequency primarily determined by the resonant frequency of the resonator and secondarily by the transit time of the electrons in the retarding field which is in turn a function of the spacing of the repeller 33 and grid 32 and of the poten-

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tials of this grid and of the repeller electrode. The coaxial structure 25, 26 is designed to have a natural fundamental resonance at the frequency of the desired oscillations. As will be apparent the outer conductor 26 is extended as at 26' an additional distance sufficient to constitute a cylindrical wave guide having a low pass cut-off in excess of the oscillation frequency so as to preclude loss of oscillation energy from the open end of the coaxial resonator.

In order to provide an oscillation output circuit, a coaxial conductor system 37, 38 is connected to the resonator at an aperture at one side of the cylinder 26, the inner tubular conductor 37 passing through the aperture and connecting electrically with the inner conductor 25 of the resonator while the outer conductor 38 is connected electrically to the outer conductor 26 of the resonator. The polarizing lead for the repeller 33 passes out through the inner tubular member 37 and leaves it by way of a coaxial stub circuit 39 which may be designed in accordance with well-known principles to act as a shunt choke circuit that will not withdraw oscillation energy from the output coaxial 37, 38.

Tuning of the oscillator may be effected by motion in either longitudinal direction, indicated by the double arrow, of a ring 40 of dielectric material encompassing the inner conductor 25. This ring has the effect of altering the electrical length of the coaxial resonator without, however, permitting the natural frequency thereof to extend into the range above the cut-off of the cylindrical wave guide. To manipulate the ring, stubs 41 of dielectric substance extending laterally from and integral with the ring 40 may project through slots 42 in the wall of conductor 26. The stubs may be moved manually or by any desired tuning mechanism and may be fixed in position after the tuning operation in any well-known manner. An indicator 43 cooperating with a stationary scale 44 may be attached to one of the stubs to indicate the frequency setting.

It will be apparent that the structure of Fig. 4 enables very high oscillation frequencies to be attained by the repeller oscillator without reducing the resonator to dimensions which from a mechanical standpoint would make the resonator difficult to construct or to manipulate.

Fig. 5 shows a modification of the system of Fig. 4 for producing microwaves. In this modified system the outer and inner coaxial members 44 and 45 constitute the resonator and the extension 46 of outer member 44 serves as a wave guide to prevent escape of microwave oscillations from the upper open end of the resonator. A dielectric tuning cylinder 47 fitting between the coaxial members is mounted for motion in an axial direction to tune the oscillator. The cylinder 47 is carried by a cap plate 48 and plunger rod 49 both also comprising dielectric material and the rod 49 may have an indicating pointer 50 attached thereto to indicate the frequency on a fixed scale 51. Negative biasing potential for the repeller 53 is derived over a path 54 extending by way of the central insulated conductor 55 which, associated with the outer tubular conductor 56 having centrally in-turned flanges 57 at its outer end, constitutes a quarter wavelength short-circuited line at the central microwave frequency desired and hence serves as a high impedance choke preventing the escape of microwave energy over the path 54. The conducting sleeve surrounding but insulated from

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the conductor 55 to serve as the central or inner element of the coaxial high frequency choke is connected to the inner coaxial member 45 of the oscillator resonator at a point such that for the mid-band frequency the radial field is substantially zero. Consequently, at this frequency there is no tendency for the leads to sap high frequency energy from the oscillator. With departure from the mid-band frequency this condition no longer exists but the coaxial choke effectively serves to suppress transmission of high frequency power over the range of frequencies of interest. Microwave output energy may be supplied by the oscillator over a coaxial output circuit 58, 59 coupled by a loop 60 to the internal electromagnetic field of the coaxial resonator.

The principle of an open-circuited resonator not only enables the mechanical structure to be made larger as has been indicated but it also makes for other mechanical simplification. For example, if the extension 46 be sufficiently long so that the cut-off wave guide section introduces an extremely high impedance between the outer end 61 of the wave guide and the end 62 of the coaxial resonator the nature of the outer termination of the wave guide section at 61 is of little moment from an electrical standpoint from the viewpoint of the coaxial resonator which remains open-circuited. It is accordingly feasible to close that end of the wave guide 46 with a metallic cap 62 which may cooperate to support and guide the dielectric plunger 49.

It will be understood that in the structures of both Figs. 4 and 5 the "open ended" portion of the coaxial resonator is so designed as to comprise substantially a quarter wavelength structure at the mid-frequency of the desired range. The end of the resonator to which the electron discharge tube electrodes are connected is likewise a quarter wavelength resonator mechanically shortened to take into account the loading imposed by the interelectrode capacitances. The net over-all length of the coaxial resonator is therefore somewhat less than the half wavelength ideal structure of Fig. 1 but like that of Fig. 2 is in excess of a quarter wavelength.

Fig. 6 illustrates an embodiment of the invention in which the resonator and the electron discharge device are contained within a metallic container 64. The input circuit, output circuit and the electron gun structure may be identical in principle with the corresponding elements of the Fig. 5 apparatus. However, the grids 66 and 67 which together constitute the interaction gap of the electron discharge device are differently supported by the metallic container. Grid 66 is carried by a plate 69 extending across the interior surface of the container 64 and serving to electrically close the lower end of the coaxial resonator. Grid 67 is carried at the lower end of the inner coaxial member 70 which in turn is supported by a spider structure 71 consisting of radial arms of dielectric material as is better shown in Fig. 7. The spider structure 71 is attached to and supported by a central column 72 or rod of dielectric material which in turn is attached at its upper end and supported by the end plate 73 which serves to close the upper end of the evacuated container 64. Current leads for the electron gun pass out through beads of insulating material 74 and 75 in the usual manner.

Tuning of the oscillator of Fig. 6 is effected by varying the length and consequently the

transit time of the interaction space between the grids 66 and 67 and, what is still more important, the capacitance between grids 66 and 67. This may be accomplished by varying the position of the tuning screw 76 which is supported in the bracket 77 above the end plate 73. The end plate 73 is provided with a folded or reticulated bellows portion 78 thus permitting the central part of the plate 73 to be flexed upwardly and downwardly in response to the motion of the screw 76 so as to carry with it the rod 72 of dielectric material and the attached structure consisting of the inner coaxial member 70 and the upper grid 67. The conducting choke arm 79 which surrounds the repeller lead conductor and serves to connect coaxial member 70 with the outer coaxial member 64 may be made sufficiently flexible to permit motion of member 70 and its grid 67 toward and away from the grid 66 as determined by the adjusting screw 76. As in the case of the choke of Fig. 5 the connection of the inner coaxial member of the choke to the inner coaxial member of the resonator is preferably at a point of minimum radial field at the mid-band frequency.

Fig. 8 illustrates a modification of the upper portion of the structure of Fig. 6 in which in order to increase the low cut-off frequency of the high-pass wave guide structure, the diameter of this wave guide structure is reduced. The reduced diameter portion includes in its cylindrical vertical walls a bellows 80 permitting tuning in the same manner as in the structure of Fig. 6.

The mode of the desired oscillation is the dominant mode of the coaxial resonator in which the electric vectors extend radially between the inner and outer members of the coaxial structure. This desired mode tends to impress at the contiguous end of the cut-off wave guide oscillations of the TM₀₁ mode as illustrated for example at the top of page 473, Ultra-High Frequency Techniques, Brainerd, Wheeler, Reich and Woodruff, D. Van Nostrand Company, Incorporated, 1942.

Although the invention has been illustrated and described as embodied in a reflex oscillator it will be apparent that it is capable of incorporation in various combinations utilizing coaxial resonators and particularly in such combinations in which the coaxial resonator is coupled to the electrodes of an electron discharge device to serve as a frequency selective system with a high Q at high microwave frequencies.

What is claimed is:

1. A resonator comprising a section of coaxial conductor, an electron discharge device having two perforate electrodes between which a high frequency oscillation potential exists connected respectively to the two conductors of the coaxial section near one end, the other end of the section being electrically open and the outer coaxial conductor being prolonged at its open end beyond the corresponding end of the inner coaxial conductor to constitute a cylindrical hollow pipe wave guide, the length and diameter of the said hollow pipe wave guide being such as to cause the guide

to present substantially negligible admittance at the frequency of oscillation for which the most fundamental resonance mode of the coaxial section occurs.

2. A reflex oscillator comprising a dielectric envelope, an electron gun and a repeller electrode therein, two coaxial conducting tubes fixed in position with respect to and supported by said envelope, each of said tubes having one end closed by a grid aligned between the gun and the repeller and the other end open, the outer of the tubes extending sufficiently beyond the open end of the inner of said tubes and having its internal diameter so predesigned that the extension portion serves as a wave guide having a low-pass cutoff frequency substantially higher than a fundamental mode of resonance of the two tubes when serving as a coaxial open end resonator.

3. A resonator comprising a section of coaxial conductor, an electron discharge device having two perforate electrodes between which a high frequency oscillation potential exists connected respectively to the two conductors of the coaxial section near one end, the other end of the section being electrically open and the outer coaxial conductor being prolonged at its open end a length equal to at least two times the inside diameter of said outer coaxial conductor to constitute a hollow pipe cylindrical wave guide and to minimize power loss at the said open end.

4. A reflex oscillator comprising an electron discharge device having an electron emitter, a pair of electron permeable electrodes and a repeller aligned in position with said electron emitter, a coaxial resonator having inner and outer conducting members respectively connected to said electron permeable electrodes, the outer member being longer than the inner so as to extend beyond it at the end remote from its connection to the permeable electrodes by a length equal to at least two times the inside diameter of said outer member.

5. A reflex oscillator in accordance with claim 4 and having in addition means for varying the effective electrical length of the said inner member to vary the natural resonance frequency of the coaxial resonator.

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