April 13, 1948. W. W. HANSEN ET AL 2,439,387

ELECTRONIC TUNING CONTROL

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FIG. 1

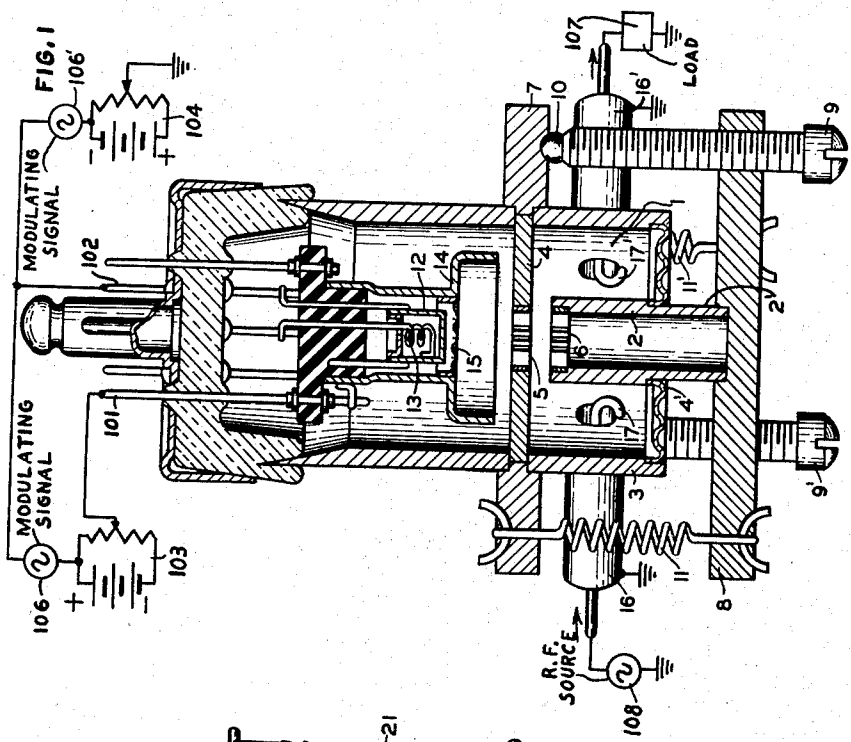


FIG. 3

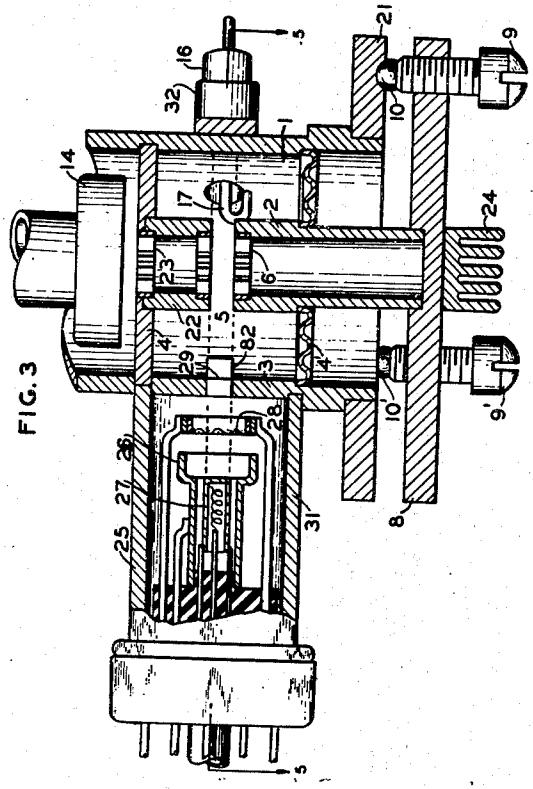
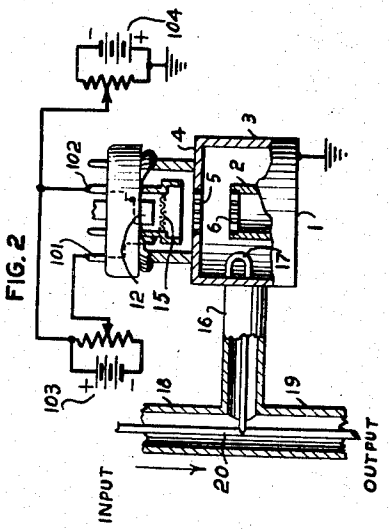


FIG. 2



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FIG. 5

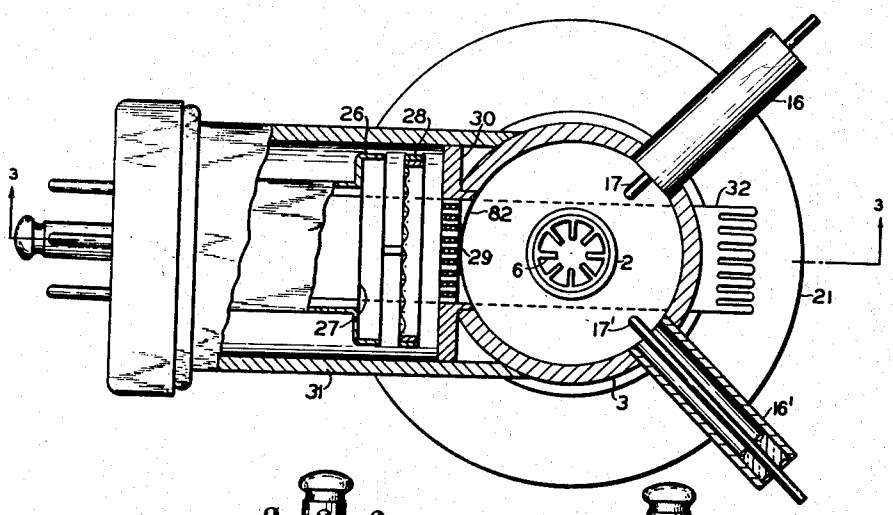


FIG. 6

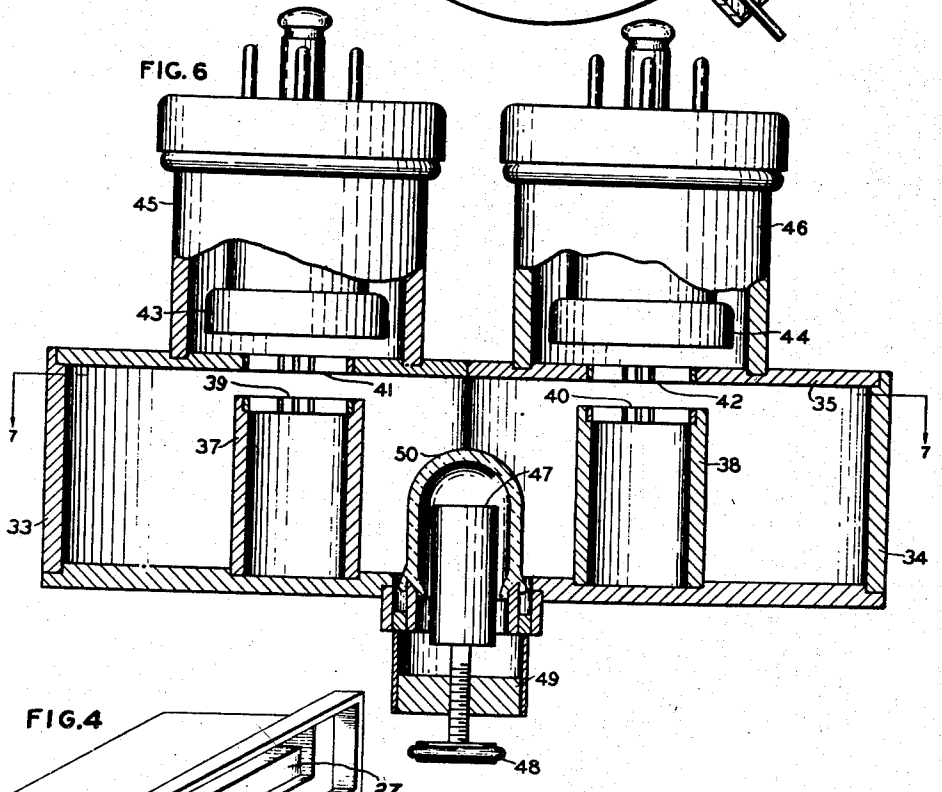
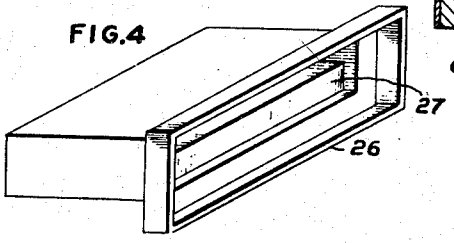


FIG. 4



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FIG. 7

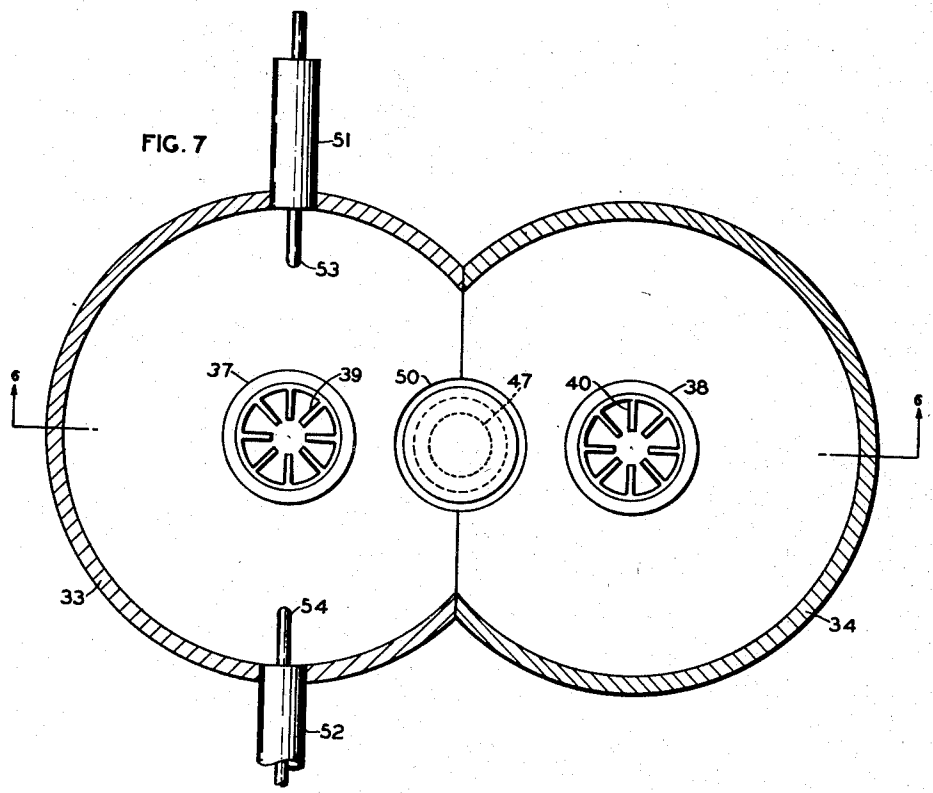
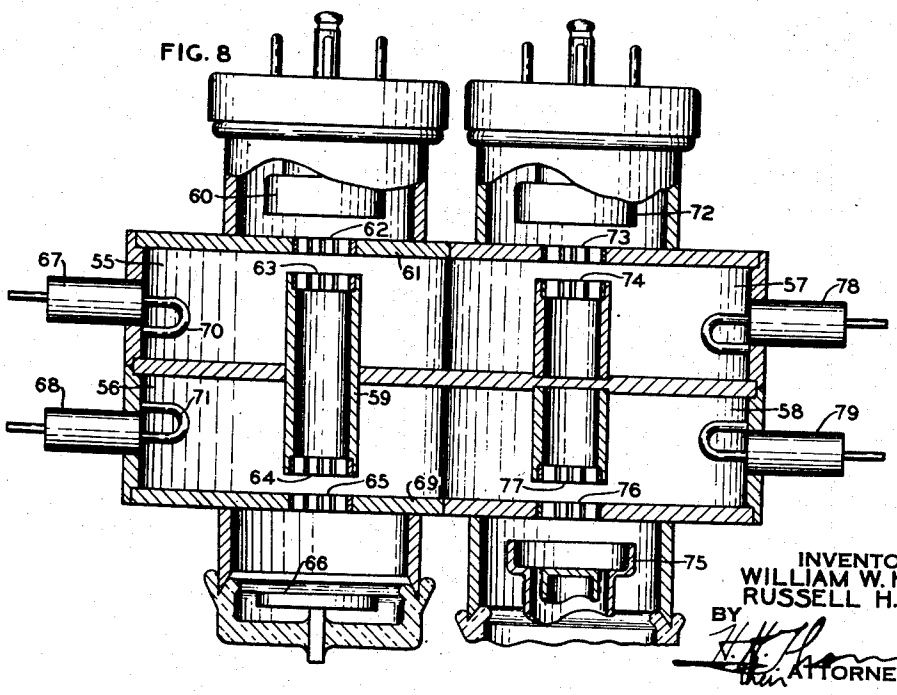


FIG. 8



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UNITED STATES PATENT OFFICE

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ELECTRONIC TUNING CONTROL

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Application November 28, 1941, Serial No. 420,770

11 Claims. (Cl. 179—171.5)

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This invention relates, generally, to ultra high frequency tube structures, and, more particularly, to novel electronic means for tuning hollow cavity resonators such as those associated with ultra high frequency tube structures of the type disclosed in U. S. Patent No. 2,242,275, for Electrical translating system and method, issued May 20, 1941, in the name of Russell H. Varian; and in U. S. Patent No. 2,242,249, for Electrical converter, issued May 20, 1941, in the names of Sigurd F. Varian and Russell H. Varian.

Effects ascribed to electron inertia have been often encountered in the design of ultra high frequency vacuum tubes. In tube structures utilizing low density electron currents at low frequencies, the effect of electron inertia is not noticeable, its importance becoming rapidly significant for higher density electron currents as impressed alternating forces are increased in frequency. For example, under certain specified conditions it has been shown that for certain space-charge-limited electron discharge tubes operated at high frequency, the value of the interelectrode capacitance may be decreased, due to the presence of the electron stream, to a value three-fifths that of the capacitance of the tube when de-energized. One may thus interpret these effects as having produced a medium between the tube elements whose dielectric constant is three-fifths. These effects have been further observed and discussed by F. B. Llewellyn in the Cambridge Physical Tract, "Electron-inertia effects," published in 1941 by the Cambridge University Press.

The principal object of the present invention is to provide electronic means whereby cavity type resonators may have their natural electrical oscillation frequency made continuously and easily adjustable by means of an electron stream of continuously adjustable density.

A further object of this invention is to provide an electronic tuning means for cavity resonators of this type so related to the resonator that the electron stream is most concentrated in the region of greatest electric flux density in the resonator, thereby effecting maximum tuning of said resonator.

Another object of the invention is the provision of a novel cavity type resonator which may be used as an adjustable filter for high frequency energy introduced therein, under the control of an electron beam.

Still another object is the provision of an electronically controlled cavity resonator filter, through which continuously adjustable amounts

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of energy may be transmitted, depending upon the density of a controlling electron beam projected therethrough.

A still further object is to provide a cavity resonator whose natural frequency may be roughly controlled by suitable means and vernier controlled by the density of an electron beam.

Another object of the invention is to provide a cavity resonator filter which may be made to control energy flow therethrough by means of an electron beam of controllable density.

Still another object of this invention is to provide a hollow cavity resonator of any desired transmission characteristic which may be made to modulate high frequency energy passing therethrough by means of a controlling modulated electron beam.

A further object is to provide such electron beam controlled cavity resonators for use in well known types of multi-resonator high frequency tube structures.

Another object is to provide an electronic frequency controlled hollow resonator, which may exercise frequency control over a second resonator coupled thereto.

A further object is to provide an electron beam controlled cavity resonator which may be so connected to a coaxial transmission line that energy flow through said line may be controlled.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 is a cross-section elevation view of a principal form of the present invention.

Fig. 2 is a view of a modification showing a specific use of the structure of Fig. 1.

Fig. 3 is a fragmentary partial cross-section elevation view of an alternate form of Fig. 1.

Fig. 4 is a perspective view of a detail of the structure of Fig. 3.

Fig. 5 is a partial cross-section plan view taken along the line 5—5 of Fig. 3.

Fig. 6 is a partial cross-section elevation view of another form of our invention.

Fig. 7 is a cross-section plan view taken along the line 7—7 of Fig. 6.

Fig. 8 is a fragmentary partial cross-section elevation view showing an application and modification of the structure of Fig. 6.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

Referring to Fig. 1, there is shown an evacuated cavity resonator 1 of the type shown in U. S. Letters Patent No. 2,311,658, issued February 23, 1943, which resonator consists of an inner conducting tubular member 2, an outer conducting tubular member 3 concentric thereto, a flat apertured end wall 4 perpendicular to and concentric with the axis of tubular members 2 and 3, and a thin flexible conducting end wall 4' also perpendicular to and concentric with said axis. Tubular member 2 projects into resonator 1 and carries a grid structure 6 in its inner end. A grid structure 5 is placed in the aperture of wall 4 opposite grid 6, grids 5 and 6 being placed at a desired close spacing, their structure being similar to that shown in plan in Fig. 5.

Extending radially from wall 4 is a flange member 7, which is parallel to a disk member 8, member 8 being carried at its center by an extension 2' of tube 2 outside resonator 1. Disk member 8 threadedly carries three screws 9, 9', 9'' projecting toward flange 7, spaced at angles of, say, 120°, to each other near the periphery of disk 8. Screws 9, 9', 9'', have hardened balls 10, 10', 10'' formed or fastened on their ends, which balls are caused to thrust against cooperating spherically shaped recesses in flange 7 as by means of springs 11, 11', 11'' tending to urge disk 8 and flange 7 together. These screws 9, 9', 9'' furnish means for rough adjustment of the natural frequency of resonator 1 by distorting the flexible diaphragm 4' so as to alter the spacing between the grids 5 and 6 and to change the volume of resonator 1, thus varying the resonant frequency of resonator 1.

An electron beam is projected through grids 5 and 6 by application of a suitable acceleration voltage between grid 5 and an electron emitter button 12, which is heated by a filament 13 therein contained. This accelerating voltage is derived from the adjustable voltage source 104. A focusing shield 14 may be provided and may carry a control grid 15 to which suitable control potentials from adjustable source 103 and/or modulating potentials from modulating signal source 106 may be applied. Energy may be introduced into and/or withdrawn from the resonator 1 by means of concentric line coupling structures 16, 16' of conventional design, these concentric lines being terminated inside the resonator 1 by means of coupling loops 17, 17' respectively.

Resonator 1 may then be roughly tuned to a desired natural frequency by means of adjusting screws 9, 9', 9''. The density of the electron beam from emitter 12 is used as a readily controlled vernier tuning device, as will be described.

Let us assume that resonator 1, when no electron current flows through grids 5, 6, is sharply resonant to a frequency ω_1. When an electron current of given density is caused to flow through grids 5, 6, the effective capacitance of resonator 1 is altered accordingly, thus changing the resonant frequency of said resonator to ω_2. The resultant change occurs because the dielectric constant of the medium between grids 5, 6 has been altered due to the presence of the electron beam. In addition to producing a change in dielectric constant, resulting in a change in resonant frequency, the electron beam also decreases the Q (ratio of stored energy to energy dissipated per cycle) and lowers the effective shunt impedance of the resonator viewed at the coaxial line terminals. This "loading effect" of

the beam varies with the beam current and beam-accelerating voltage.

Resonator 1 is made reentrant in such a manner that the controlling electron beam passes through the region of highest electric flux density, which is well known to be concentrated between the grids 5 and 6 for such a shape resonator. In this manner, when the electron stream passes through these grids, the resulting resonant frequency ω_2 depends upon the density of the stream which may be controlled by the potential applied to grid 15. This electron stream or beam passes through the electromagnetic field for tuning purposes only. In other words, the beam serves its function only in the field of the resonator.

If the resonance curve of resonator 1 be made sharply resonant at ω_1, and energy of frequency ω_1 from a source 108 is introduced through coaxial transmission line element 16, the amount of ω_1 energy removed from resonator 1 by means of coaxial element 16' may be made continuously variable by providing a continuously variable voltage between emitter 12 and grid 5 from source 104 or between emitter 12 and control grid 15 from source 103.

It will be evident that any desired type of time function of amplitude may be applied to the output energy removed by means of coaxial element 16' and supplied to a load indicated at 107, by application of suitable voltages to the emitter 12 or to a control grid such as 15. Sources for such voltages are indicated by the modulating signal sources 106, 106' and the adjustable voltage sources 103, 104. Thus the present device may serve as a modulator, as a filter whose attenuation is time variable, as a filter with variable attenuation in both directions as a function of time, or as a continuously variable or adjustable attenuator, at will.

The resonator 1 may be supplied with one concentric line coupling element 16, or a plurality of such elements. With one such concentric line element 16, the resonator may, by means of a concentric line of suitable length adapted to connect with element 16, be coupled to any other type of suitable resonator, of approximately the same natural frequency, such as the "buncher" resonator of an ultra high frequency velocity modulating tube such as shown in the aforementioned Patent No. 2,311,658. Tuning of resonator 1 by the described electronic means then causes a tuning effect in the "buncher" resonator of the aforementioned velocity modulating tube. A similar external frequency-controlling resonator may be coupled to the "catcher" resonator of said velocity modulating tube. These two frequency controlling resonators may be simultaneously controlled by means of their grid potentials thereby affording means for gang and/or individual tuning of the resonators of the velocity modulating tube. The passage of different frequencies in different directions through resonator 1 can be controlled by the electronic tuning means shown, the particular frequency passed at any time depending upon the tuning of the resonator.

A further application of the type of adjustable-frequency resonator shown in Fig. 1 is illustrated in Fig. 2, wherein such a device is shown with only one coaxial line coupling element 16, which is extended and joined in shunt as a T-junction 20 to a second coaxial line 18. By suitable adjustment of the length of line 16 and the size of coupling loop 17, the impedance of line 18 look-

ing toward the T-joint 20 from the input end of line 18 can be made zero when the electron beam in resonator 1 has a particular magnitude and can be made to be of some arbitrary high resistance when the electron beam has a different magnitude. In the first case, input energy will be substantially entirely reflected at the joint 20; in the latter, energy will pass on through the junction 20 and out of line 19. By suitably adjusting the aforementioned parameters, by adjusting the sources 103, 104, any desired amount of energy may be passed through junction 20 at either time; i. e., when the beam is on or off. Hence, resonator 1 and its circuit act as a type of high frequency valve or controllable filter for a concentric transmission line.

As previously mentioned, it is desirable to have the tuning electron beam pass through the region in the resonator in which the electric flux density is maximum. To accomplish this purpose it is not necessary to pass said tuning beam axially along the electric flux between the grids 5, 6 of resonator 1 as in Fig. 1; in general, the tuning beam may pass through this region of high electric field at any suitable angle. In fact, for certain applications to be later discussed, it is desirable to use the beam passing through grids 5, 6 for velocity modulation by the action of the high frequency alternating field between grids 5, 6, and then to cause it either to pass on into an enclosing drift tube and then to resonators spaced further down said drift tube, or to be reflected back into this field as in tube structures shown in the aforementioned Patent No. 2,311,658 and in our U. S. Patent 2,250,511, issued July 29, 1941. It is therefore necessary to provide a separate beam, one preferably not passing through grids 6, 5, to function as a tuning ray.

A structure suitable for performing such functions is shown in Figs. 3, 4, and 5. The design of resonator 1 here is very similar to that of resonator 1 in Fig. 1 except in minor detail. Inner reentrant conducting tube member 2 extends into the resonator slightly less than half the inner axial length of resonator 1. A second reentrant tubular member 22 extends from wall 4 toward member 2 an equal length into resonator 1, so that the region of high electric field intensity is now in the geometrical center of resonator 1, rather than adjacent to wall 4. Smoothing grid 23, similar to grid 6, is placed in the end of tube 22 flush with the cathode side of wall 4.

The electron beam from cathode 14 may or may not now function as an electronic tuning device, as other means presently to be described are provided for that function. Flanges 8 and 21 cooperate with screws 9, 9', 9'', and hardened balls 10, 10', 10'', to provide a rough mechanical tuning means as before described. Springs 11 are not shown but may be used.

As shown in Figs. 3 and 5, rectangular or oval metallic member 31 is attached to and extends radially from one side of tubular wall member 3. Wall 3 is provided with a cross slot 82, wherein is embedded slotted member 30 containing grid structure 29. The grid 29 is composed of conducting bars which extend parallel to the axis of the resonator 1, which is the direction of flow of the ultra high frequency currents on the inner surfaces of wall 3. In alignment with slot 82 is control grid 28 and emitter surface 27, which is contained in focussing shield 26, but insulated therefrom.

As seen in Fig. 4, emitter surface 27 and its associated shield 26 are made rectangular in

shape, so that an electron beam of width comparable to the diameter of the high electric flux density region between grids 5 and 6 and of height slightly less than the spacing between said grids, may be obtained. The electron beam from emitter 27 may be controlled in intensity by controlling the potential of grid 28, in a manner similar to the control of the beam of Fig. 1, thereby altering the resonant frequency of the resonator 1 of Fig. 5.

It will be evident that the cathode structures of Figs. 1 and 3 may be replaced by any suitable type of focussing cathode, as may those of structures to be further described. It will also be evident that tuning devices such as shown in the aforementioned Patent No. 2,242,249, and in U. S. Letters Patent No. 2,280,824, issued April 28, 1942, and No. 2,259,690, issued October 21, 1941, may be adapted for use in place of the rough tuning devices shown in Figs. 1 and 3.

One may make use of modes of oscillation or of resonators so designed that two or a plurality of regions of high electric flux density exist with two or a plurality of electron beams each cooperating with one of said high flux density regions to achieve the purpose of the structure of Fig. 3. By way of illustration of this fact, one such arrangement is shown in Figs. 6 and 7, wherein two regions of high flux density are attained. Resonators 33 and 34 are each very similar in construction to the resonator 1 of Fig. 1, an arc of roughly 80° having been cut off the cylindrical side wall and end plates of each of these resonators. The surfaces defined by the chords of this arc are then fixed permanently together face to face. Each of resonators 33 and 34 may be excited in a mode exactly similar to that used in resonator 1 of Fig. 1. An opening in width equal to the common chord then exists between resonators 33 and 34, providing coupling between the two oscillating fields and determining the amplitude and phase relations between the two oscillating fields. In fact, coupled resonators 33 and 34 may be regarded as cavity resonator means containing a substantially common electromagnetic field.

The shape of end walls 35 and 36 is seen in Fig. 7, end wall 36 being shown solid rather than flexible. Reentrant tubular members 37 and 38 are located centrally in resonators 33 and 34, respectively, and support grid members 39, 40, placed closely and exactly opposite to grid members 41 and 42, respectively, these grid members 41 and 42 being placed in openings in wall 35. Cathode structures 43 and 44, placed in end bells 45 and 46, respectively, supply electron beams which may be projected through grids 41, 39, and 42, 40, respectively.

Rough tuning of both resonators 33 and 34 may be accomplished simultaneously by means of plunger 47, located centrally in the aforementioned common plane of intersection of the two resonators. Tuning plunger 47, as described in the aforementioned Patent No. 2,259,690, serves to distort the lines of electric and magnetic flux in each of the resonators, thereby, because of its symmetrical location, changing the resonant frequency of each resonator equally. More or less of conducting plunger 47 may be projected into the resonator cavity by turning screw 48, threaded into frame 49, which is in turn attached to end wall 36 by any suitable means. Glass tube 50 provides continuity of the vacuum envelope of the device. Each resonator 33, 34 may be supplied with any suitable number of coaxial line

coupling elements, such as members 51, 52 shown in Fig. 7, the inner coupling loops 53, 54 being preferably at right angles to the plane of the drawing in Fig. 7. In either or both of the resonators, a radial electron beam as shown in Fig. 4 may be used in addition to or in place of the electron beams from cathodes 43, 44.

As suggested in the discussion concerning Fig. 3, it is seen that resonator 33 of Fig. 6 may be used as the first resonator in any multi-resonator high frequency electron velocity modulating tube structure such as that shown in the aforementioned Patent No. 2,311,658, or as a resonator for a reflex oscillator as shown in Fig. 2 of U. S. Patent 2,250,511, the resonator 34 being used as a tuning control. It is obvious that the functions of resonators 33 and 34 may be interchanged. Fig. 8 shows such an electron velocity modulated device.

Referring to Fig. 8, resonators 55 and 56, connected by drift tube 59, serve as the "buncher" and "catcher" of such an electron velocity modulating high frequency tube. The electron beam from cathode structure 60 is accelerated by a unidirectional voltage between said cathode and wall 61. It is then subjected to high frequency alternating electric forces between grids 62 and 63, and is caused to velocity group itself in the drift tube 59, whereupon it gives up its energy to maintain a high frequency alternating electric field in the region between grids 64 and 65 comprising the exciting grids of resonator 56, and finally impinges upon collector electrode 66.

Electrode 66 may be replaced by a detector structure of the type shown in the aforementioned Patent No. 2,311,658, or by a third or by a plurality of further resonators. Electrode 66 and grid 65 may be omitted entirely, the electrons of the beam then impinging on the wall 69 of resonator 56 which will act as a collector. Energy from resonator 56 may be coupled back to resonator 55 by means of a coaxial conductor attached to coaxial line elements 67 and 68, these elements terminating within resonators 55 and 56 in coupling loops 70 and 71, respectively. Alternatively these resonators may be used in any suitable circuit as shown in any of the abovementioned patents and applications.

Resonator 55 is shown directly coupled to resonator 57 and, similarly, resonator 56 is directly coupled to resonator 58 by the direct method shown in Figs. 6 and 7, so that oscillating high frequency electromagnetic fields of equal intensity and phase appear in resonators 55, 57 and 56, 58, respectively. Any desirable mechanical tuning device such as shown in the previous figures or in the aforementioned patents and applications, may be used with the pairs of resonators 55, 57, and 56, 58, or may be omitted entirely, as shown in Fig. 8.

Tuning of resonator 55 is accomplished by control of an electron beam projected from cathode 72 through exciting grids 73 and 74 of resonator 57, these resonators being closely coupled by the mutual opening between them. In the same manner, tuning of resonator 56 is accomplished by means of an electron beam from cathode 75 projected through grids 76, 77 of resonator 58. Resonators 57 and 58 may be supplied with coaxial line coupling elements 78, 79, if desirable.

It will be evident to one skilled in the art that cathode structures 72 and 75 of resonators 57 and 58, respectively, may be replaced by radial-firing cathodes of the type shown in Fig. 3; in fact, this type of construction is especially adaptable to tube devices having more than two resonators cooperating with the same drift tube; i. e., of the type shown in U. S. Letters Patent No. 2,406,372, for High frequency tube structures, granted to William W. Hansen and John R. Woodyard on August 21, 1946. It will also be evident to one skilled in the art that the electronic tuning devices herein shown are adaptable for use with frequency difference stabilization systems such as shown in U. S. Letters Patent No. 2,294,942, issued September 8, 1942, as well as many other types of systems where high frequency tubes of the present type are employed.

As many changes could be made in the above construction and many apparently widely different embodiments of this 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.

What is claimed is:

1. A high frequency device comprising a transmission line, a second transmission line connected in shunt with said first line, a cavity resonator coupled to said second transmission line whereby said second line and said resonator exhibit an effective shunt impedance to said first transmission line, and means for varying said effective shunt impedance comprising means for setting up an electron beam, means for projecting said beam within said resonator, and means for adjusting the intensity of said electron beam.

2. Ultra high frequency apparatus comprising an ultra high frequency conductor, resonator means coupled to said conductor intermediate the ends thereof, and means for controlling the impedance of said conductor to flow of high frequency energy therealong, comprising means for projecting an electron stream through said resonator and means for adjusting said stream to vary said impedance.

3. High frequency apparatus comprising a source of high frequency energy, a utilization device for said energy, a resonant cavity coupled between said source and said device and adapted to contain an oscillating electromagnetic field, and means for controlling the flow of energy from said source to said device through said cavity, comprising means for projecting an electron stream through said cavity longitudinally of the electric field component of the electromagnetic field within said resonator and means for varying said electron stream to control said energy flow.

4. High frequency apparatus comprising a transmission line, a cavity resonator coupled to said transmission line intermediate the ends thereof, and means for varying the effective shunt impedance of said line, comprising means for projecting an electron stream within said resonator, and means for adjusting said electron stream.

5. Apparatus for controlling high frequency energy flow, comprising a transmission line, a cavity resonator coupled to said line at an intermediate point thereof to present an impedance in shunt therewith, and means for varying the impedance in shunt with said line presented by said resonator, comprising means for projecting a beam of electrons through said resonator and means for varying the intensity of said beam to thereby vary said impedance.

6. Apparatus for controlling the flow of high frequency energy, comprising a high frequency

energy transmission line means, a cavity resonator coupled to said transmission line means at an intermediate point thereof, means for projecting an electron stream through said resonator, and means for varying said stream to thereby control said energy flow.

7. Apparatus for controlling the flow of high frequency energy between a source and a load comprising a high frequency energy transmission line means adapted to be coupled between said source and load, resonator means coupled to said transmission line means at an intermediate point thereof, and means for varying the tuning of said resonator means in response to control signals, whereby said energy flow is correspondingly varied, said last-named means including means for projecting an electron stream within said resonator means.

8. High frequency modulating apparatus comprising a source of high frequency energy, a high frequency transmission line means coupled to said source, a cavity resonator coupled to said transmission line means at an intermediate point thereof, means for projecting an electron stream within said resonator, and means for controlling said stream in accordance with modulating signals to produce modulation of the energy flowing in said transmission line means.

9. High frequency apparatus for controlling the flow of high frequency energy along a high frequency energy transmission line means in accordance with control signals, comprising a second high frequency energy transmission line means connected in shunt with said first transmission line means, a cavity resonator coupled to said second transmission line means and comprising a pair of apertured electron-permeable walls, means including a cathode aligned with said apertured walls for projecting an electron stream therethrough, a control grid interposed between said cathode and said walls, and means for applying said control signals to said control grid, whereby the characteristics of said cavity resonator are varied in accordance with said control signals, producing a corresponding variation of the impedance presented by said cavity resonator and said second transmission line means to said first transmission line means, and thereby correspondingly controlling the flow of energy through said first transmission line means.

10. High frequency modulating apparatus comprising a cavity resonator having a pair of coaxial cylindrical walls conductively joined together at one end, an electron-permeable grid disposed across the other end of the inner of said cylindrical walls, a second electron-permeable wall mounted across the other end of the outer of said cylindrical walls and spaced from said first electron-permeable wall by a narrow gap, a cathode mounted in alignment with said electron-permeable walls and adapted to project an electron stream therethrough, a control grid

mounted between said cathode and said walls, an output coaxial line terminal coupled to said resonator, a source of ultra-high-frequency energy to be modulated, a utilization device for such modulated energy, a high frequency energy transmission line means coupling said source and said device and adapted to transfer high frequency energy therebetween, means connecting said terminal to said transmission line means at an intermediate point thereof, a source of modulating signal, and means applying said modulating signal to said control grid, whereby the energy flowing through said transmission line means is modulated in accordance with said modulating signal.

11. High frequency apparatus comprising a high frequency energy transmission line means, a reentrant axially symmetrical cavity resonator having a pair of electron-permeable walls arranged along the axis thereof, means for projecting an electron stream along said axis through said walls, means coupling said resonator to said transmission line means, and means for controlling said electron stream by control signals whereby the flow of energy along said transmission line means is correspondingly controlled by said signals.

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RUSSELL H. VARIAN.

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