May 11, 1954 L. F. SORG 2,678,404

HIGH-FREQUENCY ELECTRON DISCHARGE APPARATUS

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Fig. 1.

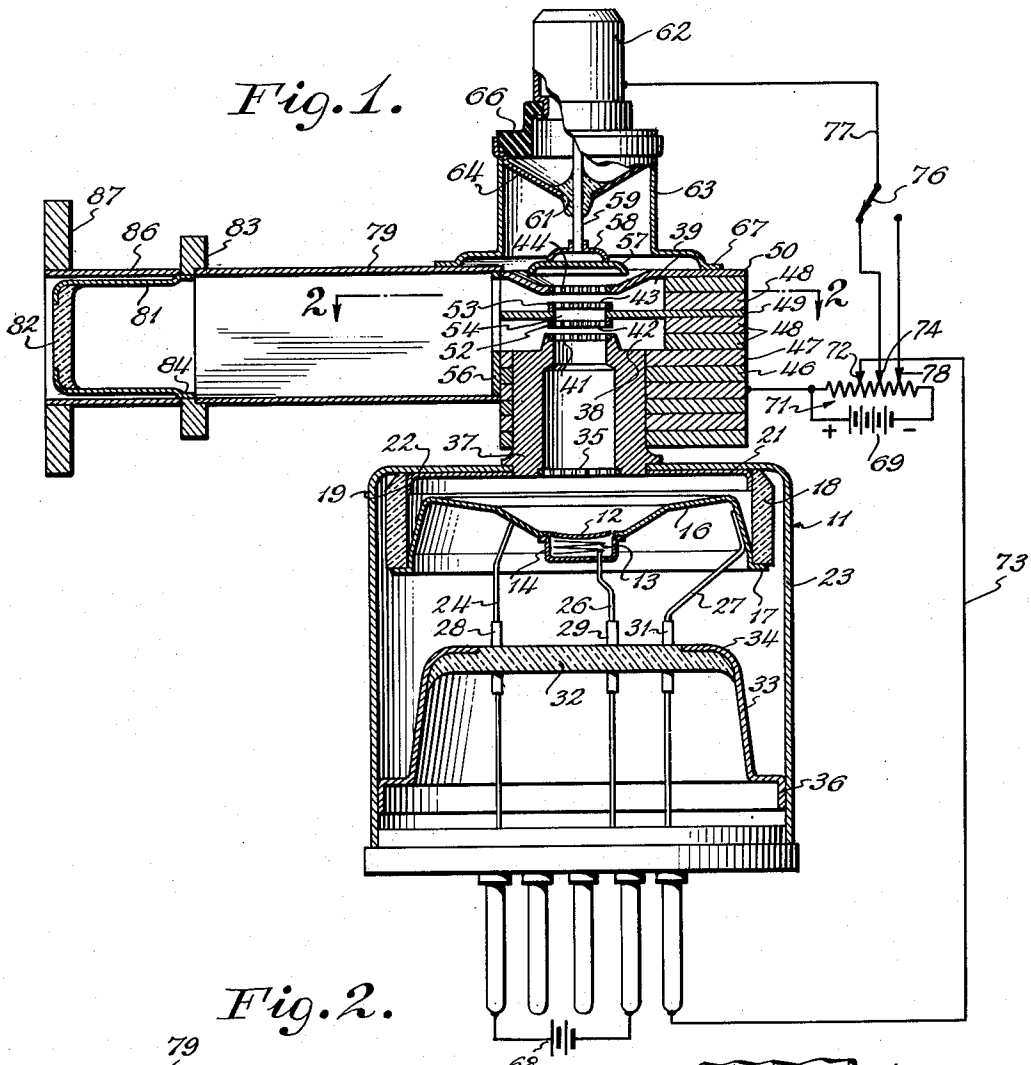



Fig. 2.

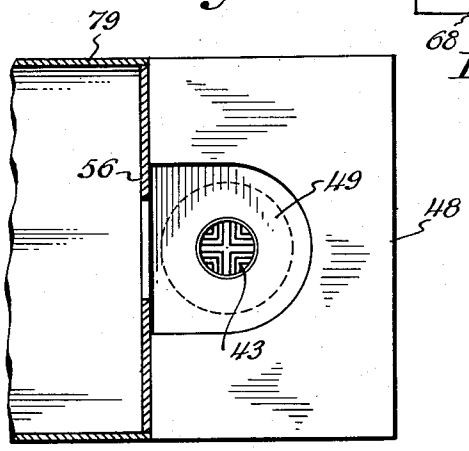
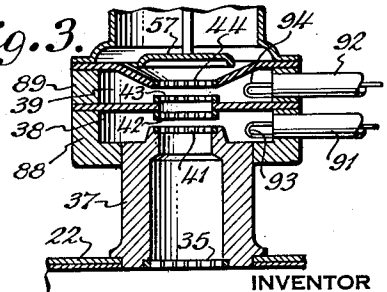



Fig. 3.




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## HIGH-FREQUENCY ELECTRON DISCHARGE APPARATUS

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4 Claims. (Cl. 315—6)

1

This invention relates generally to the production of ultra-high-frequency waves and, more particularly, to a novel form of velocity modulation electron discharge device.

Electron tube structures employing a single cavity resonator and functioning according to velocity and density modulation principles are known. In such devices an electron beam is projected in a first traverse of the resonator during which time the electron beam undergoes recurrent velocity changes. A reflecting electrode positioned beyond the resonator and in the path of the velocity modulated beam is effective for reversing the direction of the beam. In the space between the resonator and the reflecting electrode the velocity modulated electron beam becomes density modulated with the faster moving electrons transversing a greater distance than the slower moving electrons before being reversed in direction. In this manner the velocity modulated beam undergoes reflection field bunching with the formation of groups of electrons. The potential distribution is such as to reproject the density modulated beam back through the resonator with the beam giving up energy to the resonator to sustain oscillations therein. Such devices have generally been termed reflex klystrons.

According to the present invention an electron discharge device is provided with plural resonators cooperating with a unitary electron gun and reflecting electrode and operating according to velocity modulation principles. By suitable choice of operating parameters any one of the plural resonators may be excited into oscillation at a given time. With the resonators dimensioned to resonate at different frequencies a compact and efficient electron tube structure is provided suitable for generating alternatively a plurality of different frequency outputs. By properly varying the operating conditions of the device any one of the resonators may be excited independently of the other resonators to generate cyclically varying electromagnetic waves having a frequency corresponding to the resonant frequency of a particular resonator.

Accordingly it is an object of the present invention to provide an efficient and compact electron discharge apparatus suitable for alternatively generating different frequency signals.

Another object is to provide an improved electronic switching device wherein electromagnetic oscillations having different frequencies are generated in response to electrical impulses of different magnitudes.

Other objects and advantages of this invention

2

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 an elevational view, partly in cross-section, of an electron tube structure according to the present invention.

Fig. 2 is cross-sectional plan view of the device of Fig. 1 taken along line 2—2 of Fig. 1.

Fig. 3 is a fragmentary elevational view, partly in cross-section, showing a modification of the device of Fig. 1.

Referring to Figs. 1 and 2, a velocity modulation device 11 is shown having a source of electrons consisting of an oxide-coated cathode button 12, which may be energized by heater element 13. Surrounding the heater element 13 is a heater housing member 14 attached to a focusing shield 16. The cathode button 12 is secured to the focusing shield 16 and positioned within the aperture thereof by means of substantially tangentially disposed wires (not shown), the respective ends of which are fastened, as by welding, to the button 12 and shield 16.

An insulating ring 18 rests in contact along its lower surface with a radially-extending flange 17 of the focusing shield 16 and along its upper internal surface with lip portion 19 of an apertured disk 21. Disk 21 is secured, as by spot welding, to the upper portion 22 of the shell 23.

Thus, by the arrangement, the cathode button 12 is properly centered along the axis of the tube 11 by the cooperation between the insulating ring 18, shield 16 and disk 21. In addition, the insulating ring 18 serves to electrically isolate the cathode button 12 from the shell 23.

In order to provide electrical contact with the cathode button 12 and shield 16, leads 24, 26 and 27 having portions 28, 29 and 31, respectively, which are formed preferably of a material, such as Kovar, having a linear coefficient of thermal expansion approximating that of a suitable glass, are made to pass through a vitreous platform 32.

To support the platform 32 within the shell 23 there is provided an annular support member 33 having a curved flange portion 34 which is secured to the platform 32. The lower end of the member 33 is formed with a lip portion 36 which is secured to the shell 23. Thus, in the lower portion of the tube 11, platform 32, annular support member 33 and the portion of shell 23 extending above the lip 36 constitute a vacuum envelope, with the respective connections being formed in a vacuum-tight manner.

A tube 37, aligned with the longitudinal axis of the tube 11, is rigidly attached to and supported by the upper portion 22 of the shell 23. Adjacent the other end of tube 37 are two means defining an electromagnetic field, such as resonators 38, 39, with resonator 38 having an electron-permeable region or gap defined by grids 41, 42. Owing to the shape of tube 37, resonator 38 is provided with a slightly reentrant configuration. Similarly, resonator 39 has an electron-permeable region or gap defined by grids 43, 44.

Both resonators 38, 39, are constituted by stacking and interconnecting suitably-formed sheets or laminations of metal. Partly surrounding the tube 37 and extending along the axis of tube 11 are metallic laminations or plates 46–50, which may be joined as by brazing with a silver-copper alloy. Plate 49 serves to define a part of the wall surfaces for both resonators 38, 39 as well as support rings 52, 53 to which are secured grids 42, 43. Thus, an electron drift space or tube 54 is formed between grids 42, 43. Plate 50 supports grid 44 and by reason of its exposed lower surface forms a part of the wall for resonator 39.

End plate 56 is suitably apertured to provide an electromagnetic energy window for coupling energy from both resonators 38, 39.

In view of the fact that the upper end of tube 37, plates 47–50, rings 52, 53, and end plate 56 form the walls of resonators 38, 39, these parts are preferably constituted of highly conductive surfaces. This may be accomplished by employing copper or copper-plated materials.

Plates 47–50 are each joined to one another in a vacuum-tight manner, as discussed above. In addition, the connections of the tube 37 to the lower plates 46 as well as the upper portion 22 of the shell 23 are similarly vacuum-tight joints.

A reflector electrode 57 is rigidly joined to a dish-shaped member 58 which is supported by a reflector lead 59 rigidly secured thereto. The lead 59 passes through glass seal 61 to effect electrical contact with cap 62.

A cylindrically-shaped sleeve 63 is attached at its upper end to a frusto-conically-shaped member 64, which member 64 is centrally-apertured and joined to seal 61. The connections between the reflector lead 59, the seal 61, the frusto-conically-shaped member 64, and the sleeve 63 are all effected in a vacuum-tight manner. In a similar manner the cooperating part of the radially-extending flange portion 67 of sleeve 63 is joined to plate 50.

To electrically isolate the cap 62 from the cylindrical sleeve 63 and the remainder of the tube 11, there is provided an annular insulating member 66. In joining the cap 62 to the insulating member 66 the end portion of the cap 62 may be spun over the insulating mmber 66.

To energize the heater element 13 leads 24, 26 are connected to a suitable source of potential, such as battery 68. The cathode button 12 is maintained at a negative potential with respect to the smoother grid 35 and resonators 38, 39 by means of a suitable source of potential, such as battery 69 and voltage-divider 71. Tap 72 of the voltage-divider 71 connects with lead 27 by means of external lead 73. The reflector electrode 57 is maintained at a potential equal to or below the value of the potential applied to the cathode button 12 by movable contact or tap 74 and external lead 77, which is connected through switch 76 to cap 62.

While tap 74 is effective through adjustment



for varying the potential applied to the reflector electrode 57, the voltage of this electrode 57 may be rapidly varied between two values by means of a further movable contact or tap 78. The switch 76 is effective for applying either of two voltages to the reflector electrode 57. This arrangement will be discussed more fully below.

To couple electromagnetic energy from the resonators 38, 39, electromagnetic coupling means, such as wave guide 79, are provided. This wave guide 79 is preferably formed with highly conductive internal surfaces, which may be accomplished by fabricating wave guide 79 from copper or a copper plated material, in order to effect an efficient transfer of energy. The end of the wave guide 79 is closed by means of a window frame 81, in which there is included a glass window 82. To facilitate the connection of the window frame 81 to the wave guide 79 a ring 83 is provided, which initially may be secured to the wave guide 79. Enlarged end portion 84 of the window frame 81 may be joined, as by soldering with a copper-silver alloy, to the ring 83. Surrounding the frame 81 is a housing member 86 joined to the ring 83, with the connection preferably being made with solder having a relatively low melting point in order to ensure that the connection between the enlarged end portion 84 of the frame 81 and the ring 83 is not thereby disturbed. At the end of the housing member 86 adjacent the glass window 82 is positioned an apertured end plate 87 rigidly joined thereto.

In view of the fact that the wave guide 79, window frame 81, glass window 82 with the cooperating action of ring 83 constitute a portion of the vacuum envelope of the tube 11, all these connections are formed in a vacuum-tight manner. In addition, the wave guide 79 is joined to the metal plates 46, 47 as well as the flange portion 67 of the sleeve 63 in vacuum-tight connections.

Owing to the configuration of the window frame 81, the joining of this part to the wave guide 79 is facilitated by connecting the frame 81 to the ring 83 at a point relatively far removed from the glass window 82, with the possibility of cracking of or other damage to the glass window 82 being minimized. Thus, the shape of the window frame 81 is such as to provide a relatively long heat flow path from the enlarged end portion 84 to the glass window 82.

In operation, the electrons emanate from the cathode button 12 and under the influence of an accelerating potential, maintained in part by the battery 69, accelerate toward the smoother grid 35 and traverse the tube 37. As a function of the magnitude of the voltage applied to the reflector electrode 57 either one of the resonators 38, 39 may be effective in the velocity modulation process.

In the event that the potential at which the reflector 57 is maintained is suitable for energization of resonator 39, the electrons after passing through tube 37, the gap defined by grids 41, 42 and drift space 54, traverse the grids 43, 44 of resonator 39. In the space between the grid 44 and the reflector electrode 57, the electrons of the beam will experience reflecting field bunching to be reversed in direction and returned to the resonator 39 to deliver electromagnetic energy thereto.

Accepted theories of the foregoing action based on velocity modulation principles are explained fully in Fig. 2 of United States Patent

No. 2,250,511, issued July 29, 1941, to Russell H. Varian and William W. Hansen.

With regard to the action of the electrons in the velocity modulation process as associated with resonator 39, an electron that has been accelerated by the action of the radio frequency field maintained in resonator 39 will travel farther into the reflecting field and will take longer than the average time to return to the resonator 39. An electron leaving the resonator 39 at a time when the radio frequency voltage therein is zero and changing from acceleration to deceleration requires an average transit time. An electron which passes the resonator 39 earlier in the cycle is accelerated and requires a longer time to return. Moreover, an electron that traverses the resonator 39 later in the cycle requires less than the average transit time. All these electrons return to the resonator in a bunched condition at a later time. Thus, by the velocity modulation action of the resonator 39 grouping of the electrons of the beam results, and as a consequence, the uniform flow of beam current is converted into an equivalent direct current with a superimposed alternating component.

Since a maximum retarding field is required for maximum energy transferred from the bunched beam, the transit time for an electron that enters the reflecting field with average velocity must correspond to one quarter cycle less than an integral number of cycles.

With regard to resonator 38, it will be noted that electrons passing grid 42 thereof are not immediately brought under the influence of the reflection field. Such electrons traverse the drift space 54, and the gap of resonator 39, defined by grids 43, 44 before entering the reflection field provided in part by the reflector electrode 57. The electrons in passing through the electron permeable region of the resonator 38 are subjected to velocity modulation in their initial transit, that is, from the cathode button 12 toward the reflector electrode 57. After passing the grid 42, such electrons pass through the field free drift space 54 and grids 43, 44 to undergo field free bunching prior to the time reflection field bunching occurs. The expression "field-free," as used above, and as used through out the rest of the specification and chaims, is intended to mean free of any reflection fields and is not intended to exclude magnetic fields as might be employed in focussing the electron beam as is found in some electron discharge apparatus.

In the region between the grid 44 and the reflector electrode 57 the velocity modulated electrons experience reflection field bunching, with the faster moving electrons traversing a greater distance before being reversed in direction. As a result, a bunched electron beam is formed.

After passing grid 44 the electron beam, having been reversed in direction, passes through the grids 44, 43 and drift space 54 before traversing the gap of resonator 38 defined by grids 41, 42, where energy is extracted by resonator 38 to sustain oscillations therein.

Thus, the electron beam in the case of excitation of resonator 38 undergoes reflection field bunching as well as field-free bunching, the latter occurring between grids 43, 44 and in drift space 54. The field-free bunching is similar to the process which occurs for instance, in a dual resonator klystron, such as shown in U. S. Patent No. 2,242,275, entitled "Electrical Translating System and Methods," in the name of R. H. Varian.



A review of both types of bunching in physically separate and distinct velocity modulation devices reveals that the current distribution in a reflected bunch is similar to that in the field-free case, but that the manner in which the electrons reach this distribution is decidedly different. In the field-free case an infinite current peak exits prior to the time the electrons arrive at the gap of the output or energy-extracting resonator. The electrons traveling in the beam pass one another, with the infinite current peak separating to form a large but finite current peak between two diverging infinite current peaks.

In reflection field bunching, which occurs in a reflex klystron, a similiar current distribution results. However, there is no single infinite current peak formed prior to the formation of a double infinite current peak. If the magnitude of the velocity modulation remains the same, introducing both types of bunching in the same tube results in a decreased output owing to the fact that the two effects are out of phase.

Thus, an important consideration of the instant invention is that of providing a minimum length drift space, such as drift space 54, which is approximately the same in length as the extent of either of the electron permeable regions of resonators 38 and 39. This is desirable in order to ensure a relatively large magnitude of output power from resonator 38. This consideration should be consistent with mode separation, as discussed below.

Another consideration with regard to the instant invention is that of maintaining a maximum separation between the modes at oscillation of the separate resonators 38, 39. In "Klystron Tubes," A. E. Harrison, McGraw-Hill Book Company, Inc., 1947 at page 98 there is shown in Figs. 7–8, a power output vs. reflector voltage characteristic. The action of the reflex klystron is such that distinct modes of oscillation occur at different values of the reflector voltage. Oscillations take place with varying magnitudes of reflector voltages when the transit time for the electrons has changed by an amount equivalent to one complete cycle. In the instant device 11, in order to prevent both resonators 38, 39 from oscillating simultaneously, the modes of oscillation of the two resonators 38, 39 must not coincide or overlap to an appreciable extent.

In practice, it has been found possible to achieve the desired result. However, it is desirable to employ a relatively high accelerating voltage to ensure a relatively high output power from resonator 38.

In Fig. 3 there is shown a modification of the device of Figs. 1 and 2, in which the walls of the resonators 38, 39 are formed somewhat differently. Tubular members 88, 89 serve to define the side walls of the resonators 38, 39, respectively. In addition, coupling means, such as coaxial transmission lines 91, 92 with their coupling loops 93, 94, respectively, are employed for coupling energy from resonators 38, 39, respectively.

An important advantage of the laminated construction of the side walls of the resonators 38, 39 as shown in Figs. 1 and 2 is that resonators of different dimensions may be more readily fabricated from existing parts. For instance, a resonant chamber of larger volume may be fabricated by employing an additional plate, such as plate 48. Thus, velocity modulation de-

vices suitable for providing a wide range of different frequencies are more readily constructed.

It is, of course, understood that the coaxial transmission lines 91, 92 may be employed in place of wave guide 79 for coupling energy from the resonators 38, 39 of Figs. 1 and 2. Similarly, the wave guide 79 may be employed for a similar purpose with the resonator construction of Fig. 3.

While no tuning mechanism has been shown for adjusting the frequency during operation of the resonators 38, 39, it was found possible by pre-tuning the resonators 38, 39 during fabrication to obtain a frequency separation of 180 megacycles between the resonator frequency of resonators 38, 39, with operating frequencies having wavelengths in the neighborhood of 3 centimeters. The pre-tuning of the upper resonator 39, for instance, was accomplished by adjusting the spatial separation of the grids 43, 44 with a hydraulic press.

It is, of course, understood that the invention may be employed with vastly different operating frequencies as well as significantly different frequency separations between resonators, such as resonators 38, 39.

If desired tuning mechanism may be employed in conjunction with the resonators 38, 39. For instance, the tuner shown in application Ser. No. 725,106, in the name of Marvin Chodorow, filed January 29, 1947, issuing as Patent No. 2,617,071 on November 4, 1952, may be employed. Also, if desired, other tuning arrangements similar to those shown in U. S. Patent No. 2,230,824, entitled "Radio Transmission and Reception," issued April 28, 1942, in the name of W. W. Hansen et al., may be used.

The present invention lends itself to a switching mechanism arrangement, in which high frequency signals of different frequencies are generated in response to electrical impulses of different magnitude. Thus, a signal having a predetermined frequency may be produced as a result of a direct current potential of selected magnitude, whereas a signal having a different frequency may be generated as a function of a similar-type potential of a different selected magnitude. Such potential may, for instance, be applied to the reflector electrode 57 in substitution for the voltage-divider 71, switch 76 and structure associated therewith.

While the invention has been described in connection with two resonators 38, 39, it is of course understood that a multi-resonator structure may be employed, in which the separate resonators have spaced resonant frequencies. With such an arrangement, to separately excite the various resonators, a multi-switch arrangement would be suitable for obtaining the proper reflector voltage from a voltage divider such as voltage divider 71.

While the invention has been described in terms of a reflector voltage variation to obtain the selective energization of the resonators 38, 39, it is of course understood that other operating voltages might be systematically altered to obtain the same result. For instance, the accelerating voltage, such as the voltage applied by the smoother grid 35 and the cathode button 12 by means of voltage divider 71 and tap 72, might be varied to separately and selectively excite resonators 38, 39. In such case, a switch similar to switch 76, together with cooperating movable contacts associating with the voltage divider 71, might be introduced into the external lead 73.



It is also apparent that both the reflector and the accelerating voltages might be adjusted simultaneously to different values to achieve the present invention.

While the internal parts of tube 11 have been shown in Figs. 1 and 3 as symmetrically disposed about the longitudinal axis of the tube 11, it is understood that Figs. 1 and 3 may be regarded essentially as figures of translation rather than figures of revolution.

It appears that many changes could be made in the above-described construction including, for instance, the resonator construction, the electromagnetic coupling means, the number of resonators employed, the operating voltages selected to be adjusted, and switching mechanism arrangement. Since many 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 reflex klystron generator for selectively providing microwave energy of a first predetermined frequency or microwave energy of a second predetermined frequency distinct and separate from said first frequency, comprising first and second cavity resonators each having an electron permeable region aligned along an axis, means for producing and directing an electron beam along said axis for progression through said electron permeable regions of said cavity resonators, means defining a reflection field-free drift space along said axis between said electron permeable regions, a reflector electrode positioned along said axis beyond said electron permeable regions for reflecting electrons directed along said axis, means for applying uni-directional voltages to said means for producing and directing said electron beam and said reflector electrode to sustain oscillation of microwave energy in said first cavity resonator with energy derived from said electron beam, means for changing the relationship between said unidirectional voltages to selectively sustain oscillation of microwave energy in said second cavity resonator with energy derived from said electron beam, the length of said means defining said field-free drift space being approximately the same as the extent of either of said electron permeable regions along said axis whereby reflection field bunching of electrons effected in the field established in the vicinity of said reflector electrode is appreciably greater than field-free bunching of electrons in said field-free drift space effected when said first cavity resonator is energized.

2. Apparatus as defined in claim 1 wherein said resonators have different resonant frequencies.

3. High frequency electromagnetic energy generating apparatus comprising means including a cathode and anode for producing and directing an electron beam along an axis, a reflector electrode spaced an appreciable distance from said cathode along said axis, said electrode comprising means for producing an electric field for repelling the electrons of said beam toward said cathode, a first cavity resonator tuned to a first resonant frequency having an electron permeable region positioned along said axis between said cathode and said reflector electrode, a second cavity resonator tuned to a second resonant frequency and having an electron permeable

region positioned along said axis between the electron permeable region of said first cavity resonator and said reflector electrode, the distance along said axis between said electron permeable regions being approximately the same as the extent of either of said electron permeable regions along said axis, and means connected to said reflector electrode for energizing said electrode with a uni-directional voltage to produce a reflection field for said electron beam in the vicinity of said reflector electrode.

4. High frequency electromagnetic energy generating apparatus as defined in claim 3 wherein said means for energizing said reflector electrode includes switching means for changing the unidirectional voltage applied to said reflector electrode to selectively sustain electromagnetic oscillations in said first or said second cavity



resonators by selective interaction of said cavity resonators with said electron beam.

**References Cited** in the file of this patent

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 2,314,794 | Linder | Mar. 23, 1943 |
| 2,323,729 | Ryan | July 6, 1943 |
| 2,375,223 | Hansen et al. | May 8, 1945 |
| 2,450,023 | Spencer | Sept. 28, 1948 |
| 2,450,026 | Tomlin | Sept. 28, 1948 |
| 2,466,059 | Spencer | Apr. 5, 1949 |
| 2,468,145 | Varian | Apr. 26, 1949 |
| 2,485,400 | McArthur | Oct. 18, 1949 |