March 31, 1959 D. L. SNOW ET AL 2,880,357

ELECTRON CAVITY RESONATOR TUBE APPARATUS

Filed Oct. 21, 1955 2 Sheets-Sheet 1

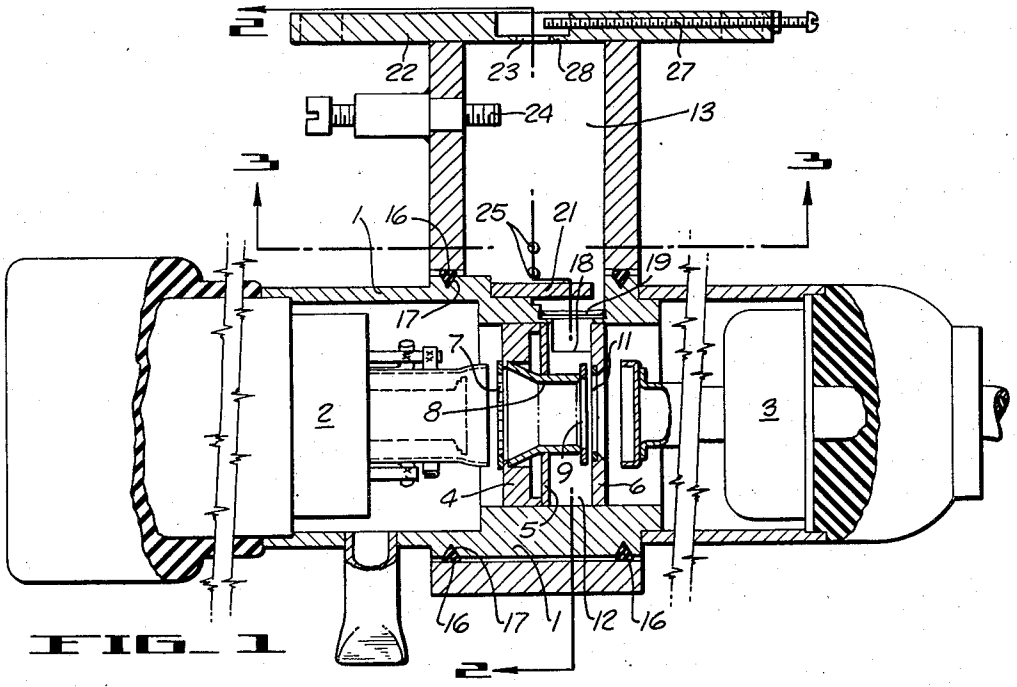


FIG. 1

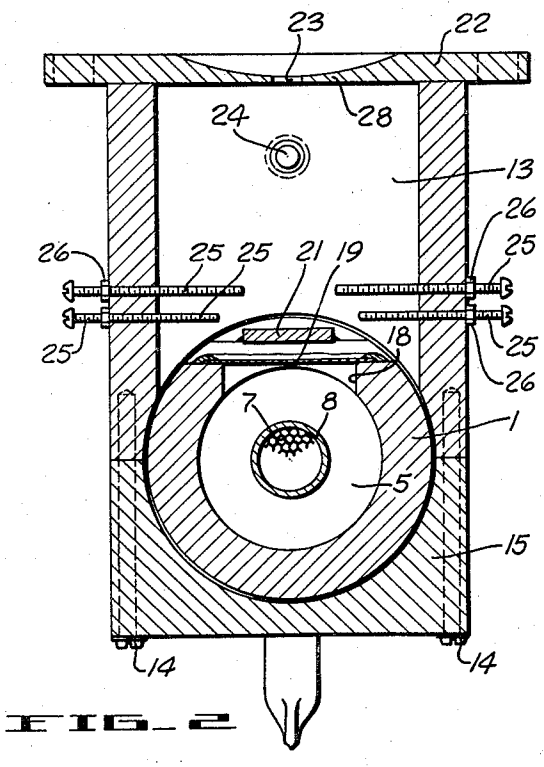


FIG. 2

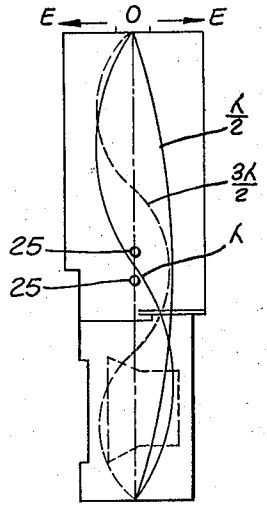


FIG. 1A

DONALD L. SNOW
PETER H. KAFITZ &
CLIFTON G. ROCKWOOD
INVENTOR.

BY Paul B. Hunter,
ATTORNEY

March 31, 1959 D. L. SNOW ET AL 2,880,357

ELECTRON CAVITY RESONATOR TUBE APPARATUS

Filed Oct. 21, 1955 2 Sheets-Sheet 2

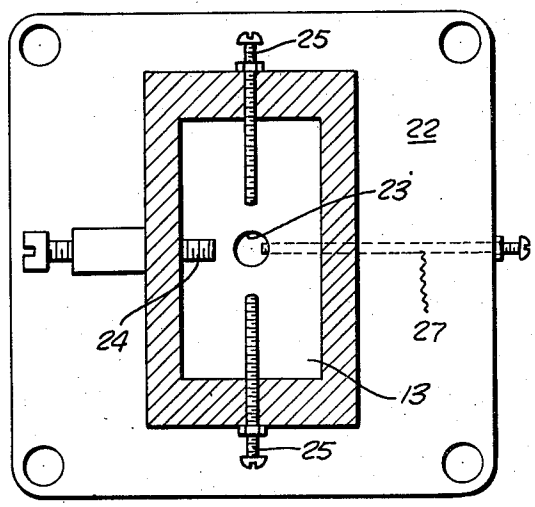


FIG_3

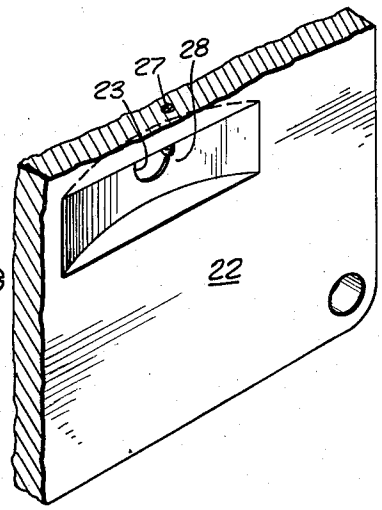


FIG_4

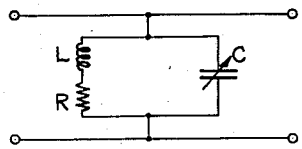


FIG_5

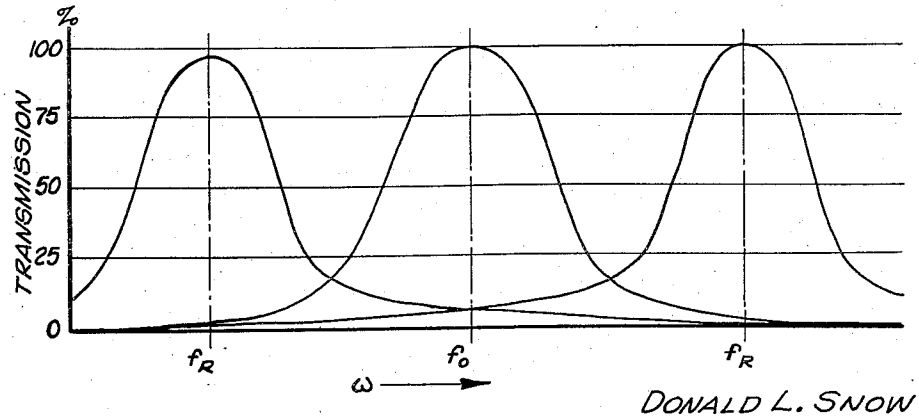


FIG_6

DONALD L. SNOW
PETER H. KAFITZ &
CLIFTON G. ROCKWOOD
INVENTOR.

BY Paul B. Hunter
ATTORNEY

United States Patent Office 2,880,357 Patented Mar. 31, 1959

2,880,357

ELECTRON CAVITY RESONATOR TUBE APPARATUS

Donald L. Snow, Palo Alto, Peter H. Kafitz, Mountain View, and Clifton G. Rockwood, Palo Alto, Calif., assignors to Varian Associates, San Carlos, Calif., a corporation of California

Application October 21, 1955, Serial No. 541,907

15 Claims. (Cl. 315—5.23)

This invention relates in general to electron tube apparatus and more specifically to novel, improved velocity modulation devices utilizing cavity resonator means, for example, klystron tubes useful as oscillators, amplifiers, modulators, frequency multipliers, etc.

The present invention, although applicable generally to klystrons, is especially useful in klystron tubes made having resonator means comprising an evacuated internal cavity closely coupled through a vacuum seal to an external cavity, the external cavity being free of the vacuum and providing a simple and dependable means for tuning the tube. Such klystron tubes are described in a co-pending application entitled "High Frequency Device," Serial No. 301,628, inventors—Sigurd F. Varian and Donald L. Snow, filed July 30, 1952, and now issued as U.S. Patent 2,789,250.

With the advent of higher frequency klystron tubes the physical size of their internal cavity resonators have been decreasing. At the present time, extremely high frequency klystrons have very small internal physical dimensions. The thermal environment of such devices has a substantial effect upon the resonant frequency of the device. Several bi-metallic temperature compensating schemes have been successful for relatively large cavities operating at low frequencies. However, at very high frequencies, although the size of the cavity is considerably smaller, the temperature compensating members required to give the necessary corrective differential dimensions must necessarily still be of a substantial size. The present invention supplies a novel temperature compensating structure for klystrons having small cavity resonator dimensions.

In klystrons of the aforementioned type, as well as in many other types of resonator devices, several possible modes of oscillation may exist concurrently. Depending upon how the cavity resonator is excited, any one of the possible modes may be the excited mode thereby introducing a degree of uncertainty as to which mode the device is operating in. In the past, several rather elaborate schemes, including mode suppression cavity resonators arranged to couple to various unwanted modes, have been employed to eliminate or suppress the unwanted modes. In this invention, novel simplified mode suppression apparatus is introduced.

In klystrons of the internal-external cavity type, it is desirable to be able to simply and efficiently change the coupling between the klystron and the load or to match the impedance of the klystron to the impedance of the load to obtain broader band width. This invention provides a novel method and means for enhancing the load coupling and impedance matching characteristics of the klystron.

Accordingly, it is the principal object of the present invention to provide a novel improved electron tube apparatus having improved thermal, mode suppression, and load coupling characteristics whereby stable, dependable, and efficient electrical performance under adverse environmental conditions is produced.

One feature of the present invention is a novel bimetallic temperature compensated cavity resonator including a novel cavity header whereby the electrical dimensions of the cavity resonator may be maintained small enough for high frequencies but still allowing sufficient size of the temperature compensating members to obtain adequate temperature compensation.

Another feature of the present invention is a novel mode suppression member positioned in an inwardly protruding manner at certain positions in a cavity resonator device thereby greatly enhancing electrical stability of the device.

Another feature of the present invention is a novel capacitive loading member in cooperation with the output iris of the external cavity resonator whereby the coupling between the electron tube apparatus and the load may be adjusted or the sending end impedance of the tube matched to the load for increasing the band width of the tube apparatus.

Other features and advantages of this invention will become apparent from a perusal of the specification taken in connection with the accompanying drawings wherein,

Fig. 1 is a longitudinal cross sectional view of a novel reflex klystron incorporating the features of the present invention,

Fig. 1A is a schematic diagram of the coupled internal and external cavity resonators of Fig. 1,

Fig. 2 is a transverse cross sectional view of the structure of Fig. 1 taken along line 2—2 in the direction of the arrows,

Fig. 3 is a cross sectional view of the external cavity resonator structure of Fig. 1 taken along line 3—3 in the direction of the arrows,

Fig. 4 is a fragmentary perspective view of the output flange portion of Fig. 1,

Fig. 5 is an equivalent dircuit of the external cavity output iris, and

Fig. 6 is a transmission versus frequency diagram of a tube apparatus as shown in Fig. 1.

Referring now to Figs. 1 and 2 there is shown a hollow open-ended cylindrical metallic tube envelope **1**. A cathode assembly **2** closes off one end of the tube envelope **1**. Closing off the other end of the tube envelope is a reflector assembly **3**. Disposed within the tube envelope **1** between the cathode assembly **2** and the reflector assembly **3** are three centrally apertured transverse metallic wall members or headers, anode header **4**, cavity header **5**, and reflector header **6**. Anode header **4** is of thicker wall construction than the other headers **5** and **6** and its central aperture is provided with a plurality of inside step portions of increasing inside diameter. A honeycombed accelerating grid **7** is fixedly secured over the central aperture on the side of the anode header adjacent the cathode assembly **2**.

A flared re-entrant drift tube **8** made of a material having a low coefficient of heat expansion, for example molybdenum, is fixedly carried at its flared end by an inside step portion of anode header **4**. Cavity header **5** is secured at its outer periphery to the tube envelope **1** where it also abuts anode header **4**. The inside periphery of cavity header **5** is secured, as by brazing, to re-entrant tube **8** substantially midway its length. A honeycombed resonator grid **9** is mounted over the free end of drift tube **7**. Closely spaced from resonator grid **9** is a second resonator grid **11** carried over the central aperture in reflector header **6**. An internal cavity resonator **12** is defined and bounded by the reflector header **6**, tube envelope **1**, cavity header **5**, the free end portion of re-entrant tube **8**, and resonator grids **9** and **11**.

A rectangular external cavity resonator **13** is provided adjacent the internal cavity resonator **12** and is held in

position by a plurality of bolts 14 extending through a U-shaped clamp assembly 15. Two soft metal rings 16 encircle the exterior of the tube envelope and are retained in position by two external V-shaped grooves 17, one at either end of the internal cavity 12. The external cavity 13 and U-shaped clamp assembly 15 are pressed firmly against the soft metal rings 16 thereby forming a tight seal.

An output coupling iris 18 is cut through the tube envelope 1 and allows energy communication between the internal cavity 12 and external cavity 13. A wave-energy permeable window 19, as of mica, covers the iris opening 18 and allows a vacuum to be maintained within the tube envelope 1. A window loading member 21 is disposed outwardly of the window 19 for controlling the amount of coupling between the internal and external cavities. Closing off the outward end of the external cavity is a flange member 22 provided with a second coupling iris 23 for coupling energy from the external cavity to the load. A simple capacitive tuning screw 24 is provided for tuning the external cavity.

In operation, electrons are emitted from and focused into a beam by the cathode assembly 1. A positive potential with respect to the cathode is applied to the tube envelope and thus applied to the apertured anode header 4. This positive potential accelerates the electrons and draws them through the drift tube toward the reflector assembly 3. A negative potential with respect to that applied to the anode is applied to the reflector whereby the electrons are turned around and repelled through the internal resonator 12 a second time. In the first trip through the internal resonator the electrons are velocity modulated by interaction with the electromagnetic fields established in the internal resonator. In the transit time for the electrons to reach the reversal point and return through the internal resonator 12 they have formed more definite groups and impart additional energy to the internal cavity on their second trip therethrough. Oscillating electromagnetic fields are set up in the coupled internal-external cavity which are then coupled to the load through output iris 23. Tuning of the tube may be accomplished by rectilinear translation of the simple tuning screw member 24.

The resonant frequency of the cavity resonator 12 is determined by the dimensions of the cavity resonator and the gap spacing between the resonator grids. Generally, increasing the volume of the cavity decreases the resonant frequency while increasing the gap spacing increases the resonant frequency. As the temperature of the resonator members increases, as is often the case in operation, the volume of the resonator will tend to increase thereby tending to lower its resonant frequency. The present novel temperature compensating mechanism offsets this lowered frequency by increasing the gap spacing.

Looking now at the expansion characteristics of the particular cavity and its associated members making up the cavity we can see that the tube envelope 1 expands radially, but more important to the temperature compensating mechanism it expands longitudinally. The amount of longitudinal expansion between any two points spaced apart longitudinally on a body will vary as the longitudinal distance between the two points. Thus, in the present novel temperature compensating mechanism, the reference points which determine the resonator gap variance with temperature variance are the anode header 4 and reflector header 6 since one end of the re-entrant tube member 8 is secured on the header 4.

The re-entrant tube 8 is made of a material having a low coefficient of heat expansion such as, for example, molybdenum. To obtain a high degree of differential longitudinal expansion between the re-entrant tube 8 and tube envelope 1, the envelope is made of a material having a high coefficient of heat expansion, for example, steel. Thus, as the temperature increases, the distance

between headers 4 and 6 increases in accordance with the expansion characteristics of the steel body 1. At the same time, the length of re-entrant tube 8 increases, but proportionally less than the increase of the distance between the headers 4 and 6 and, therefore, resonator grid 9 is moved away from resonator grid 11 to thereby accomplish the necessary temperature compensation. However, if the cavity size were defined by the volume between the anode header 4 and the reflector header 6, the cavity length would be too large for the frequency range of the particular tube. To decrease the electrical length of the cavity and bring the tube within the desired frequency range, cavity header 5 is provided.

The cavity header 5 is of thinner wall construction than the anode header 4 and acts as a flexible diaphragm allowing relative motion between the drift tube 8 and the tube envelope 1 as the temperature varies. Since the temperature compensating members must carry the cavity circulating electrical currents, the headers and tube envelope have been plated with a good electrical conducting material as of copper to minimize energy losses therein.

When an external cavity is heavily coupled to an internal cavity, as in the instant case, the combined resonator acts as a single box resonator and will support several modes of oscillation having frequencies corresponding to λ, $\lambda/2$ and $3/2\lambda$ where λ is the fundamental wave length of the resonant frequency of the combined cavities. The electrical field strengths of the aforementioned modes are roughly indicated by the dotted lines of Fig. 1A.

As can be seen from Fig. 1A, the $\lambda/2$ and $3/2\lambda$ modes have maximum electric fields E at substantially the same vicinity of the cavity whereas the λ mode has substantially no electric field at this point. It has been found that by inserting, in the proper manner, a lossy member 25 into the region of strong electric fields of the unwanted mode, the unwanted mode may be heavily coupled to the lossy member 25 thereby reducing the Q of the mode and thus preventing this mode from sustained oscillation. The mode suppression member 25 may be made of a lossy material as of, for example, non-magnetic stainless steel, graphite or iron. The length of the lossy member which protrudes into the cavity resonator determines the resonant frequency of the member and its length is preferably adjusted such that the member will resonate at or near the frequency of the unwanted mode.

In addition, the lossy member should be positioned such that there will be a substantial component of electric field of the unwanted mode of oscillation parallel to the longitudinal axis of the lossy member. However, care must be exercised not to place the member precisely in alignment with the electric field for the unwanted mode will be too heavily coupled to the lossy member, the result of which is to split the unwanted mode into additional unwanted modes.

In the present tube, mode suppression members 25 are provided which protrude into the external cavity resonator 13 such that the $\lambda/2$ and $3/2\lambda$ modes have been heavily coupled thereto, thereby eliminating electrical instability of the tube caused by the possible operation of the cavity resonator on any one of these excitable modes.

Since, in fact, the coupled internal and external cavity resonators do not precisely form a box resonator, the electrical field configurations will be distorted somewhat from that of a box resonator and it may involve some experimentation to find the correct place to insert the mode suppression members 25. It would appear, from the schematic view of the coupled resonators in Fig. 1A and from a knowledge that the combined resonators oscillate in a TE mode, that there is no component of electric field of the $\lambda/2$ and $3/2\lambda$ modes parallel to the longitudinal axis of the lossy members 25. This apparent discrepancy is due to the perturbed electric fields

in the vicinity of the window loading member not shown in the schematic drawing. The mode suppression members **25** may take the form of screws, rods, plugs or the like. A screw is particularly convenient, for its depth of penetration may be easily controlled. Once the correct position and length of the mode suppression member is achieved, the member may be held in position as by a lock nut **26**, by brazing, by peening, etc.

The present novel tube apparatus also includes a novel external cavity output iris combination (Figs. 1, 3 and 4). Protruding into the external cavity output iris **23** is a capacitive iris loading member **27**. The electrical effect of this iris is depicted by the equivalent circuit of Fig. 5 wherein it is shown that the iris acts as a parallel resonant circuit shunting a two-wire transmission line. The resonant frequency f_r of the shunting iris is variable by radial movement of the iris loading member **27**.

The thickness of the output iris wall **28** in the immediate vicinity of the coupling iris is represented by a series risistance R in the inductive branch of the iris equivalent circuit (Fig. 5). Since the series resistance R varies as the thickness of the output iris wall, the output flange member **22** has been milled out to provide a thin walled portion **28** in the immediate vicinity of the output iris, thereby decreasing the series resistance and correspondingly the power losses at the iris. In addition, the iris loading member **27** and the external cavity resonator **13** are plated with a material having good electrical conductivity, for example, gold or silver.

Referring to Fig. 6, under operating conditions the resonant frequency of the iris f_r is selected for some frequency off of the resonant frequency of the tube, f_0, such that the flatter portions of the iris coupling resonant curve coincide in frequency with the frequency range of the tube. It can then be seen that by varying f_r the flat portions of the curve will move up or down with respect to the frequency range of the tube thereby controlling the coupling or transmission to the load. If f_r is selected for a value below f_0, then, over the frequency range of the tube, the impedance seen by the tube, sending end impedance, will decrease with an increase in frequency. This frequency characteristic of sending end impedance is a better match and allows wider band width than an increasing sending end impedance versus frequency characteristic.

Since 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 disclosure or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In an electron tube apparatus employing a cavity resonator device, a metallic envelope forming the side walls of the cavity resonator, a drift tube member made of a material having a coefficient of heat expansion which is lower than the coefficient of heat expansion of the material forming the side walls of the cavity resonator and said drift tube being rigidly coupled at substantially one end thereof to said envelope, a centrally apertured transverse flexible conducting wall member coupled to said envelope and said drift tube and forming one end wall of the cavity resonator, a second centrally apertured transverse wall member forming the other end wall of the cavity resonator, whereby the gap spacing of the cavity resonator can be made to increase with thermally caused increases in the physical size of the cavity resonator thereby maintaining a substantially constant resonant frequency of the cavity resonator in a changing thermal environment.

2. In an electron tube apparatus employing a cavity resonator device, a metallic envelope forming the side walls of the cavity resonator, a centrally apertured rigid anode header transversely mounted in said hollow metallic envelope, a centrally apertured reflector header longitudinally spaced from said anode header and similarly transversely mounted, a flexible centrally apertured cavity header transversely mounted in said metallic envelope and disposed between said anode and reflector headers, and a drift tube member made of a material having a coefficient of heat expansion which is lower than the coefficient of heat expansion of the material forming the cavity resonator side walls, said drift tube rigidly secured at one end to said anode header and the free end thereof extending toward said reflector header through the aperture in said cavity header whereby thermally caused increases in the size of the cavity resonator may be compensated for by an increase in the spacing between the free end of said drift tube and said reflector header to thereby maintain a substantially constant resonant frequency for the resonator in a changing thermal environment.

3. In an electron tube apparatus as claimed in claim 2 wherein said metallic envelope is made of conductive coated steel, and said drift tube is made of conductive coated molybdenum.

4. In an electron tube apparatus employing a first evacuated cavity resonator, a second cavity resonator closely coupled to said first cavity resonator via a vacuum sealed iris, a lossy probe member protruding inwardly of said second cavity resonator and disposed in the vinicity of strong electrical fields of unwanted modes of oscillation within said second cavity resonator, the longitudinal axis of said lossy probe member being positioned such as to have a substantial component of electric field of the unwanted mode parallel thereto, whereby said unwanted modes are heavily coupled to the lossy member and prevented from building up thereby effectively suppressing these undesired modes.

5. In an electron tube apparatus employing an internal cavity resonator interacting with a beam of charged particles, an iris opening in the side wall of the internal cavity, a wave-energy permeable material sealed over said iris opening and forming a vacuum tight closure, an external cavity resonator mounted adjacent said internal cavity resonator and communicating with said internal resonator through said iris opening, a window loading member mounted adjacent said iris opening, and a lossy resonant mode suppression member protruding inwardly of said external cavity resonator adjacent said wave-energy permeable material, whereby unwanted modes of oscillation are coupled thereto and prevented from sustained oscillation.

6. In an electron tube apparatus, an internal cavity resonator formed and arranged to interact with an electron beam, an external cavity resonator electrically coupled to said internal cavity resonator, an output iris means provided in an outward side wall of said external cavity resonator for coupling energy from said external cavity to a load, and a capacitive iris loading member protruding into the vicinity of said iris opening for tuning said iris opening and thereby controlling the degree of electromagnetic coupling between a load and the tube and providing a means for varying the band width of the apparatus.

7. In an electron tube apparatus as claimed in claim 6 wherein portions of the outward side wall in the immediate vicinity of said iris coupling means have been removed to provide a thinner wall portion in the vicinity of said iris means whereby the energy losses at said iris may be minimized.

8. In an electron tube apparatus, an internal cavity resonator formed and arranged to interact with an electron beam, a section of waveguide mounted adjacent the side wall of said internal cavity resonator and forming an external cavity resonator and having an open end thereto, a first coupling iris disposed in the side wall between said internal and said external cavity resonators

whereby electromagnetic energy may be transmitted through said first iris opening, a flange member closing the opened end of said section of waveguide and having a second iris opening centrally disposed therethrough, a translatable capacitive loading member radially protruding adjacent said second iris opening for varying the electromagnetic coupling between said external cavity resonator and a load, and a portion of the flange member formed to a thinner thickness in the immediate vicinity of said second iris opening thereby minimizing energy losses at said second iris.

9. In an apparatus as claimed in claim 8 wherein said capacitive loading member is a screw threaded through said flange member.

10. In an electron tube apparatus employing an internal cavity resonator for interaction with a beam of charged particles, a metallic envelope forming the side walls of the cavity resonator and having a relatively high coefficient of heat expansion, a drift tube member made of a material having a low coefficient of heat expansion and being rigidly coupled substantially at one end thereof to said envelope, a centrally apertured transverse flexible conducting wall member coupled to said envelope and said drift tube and forming one end wall of the cavity resonator, a second centrally apertured transverse wall member forming the other end wall of the cavity resonator, whereby the difference in thermal expansion of said drift tube and said metallic envelope serves to maintain a substantially constant resonant frequency of the cavity resonator in a changing thermal environment by properly varying the resonator gap spacing, an external cavity resonator closely coupled to said internal cavity resonator, lossy mode suppression probe means protruding into said external cavity resonator whereby unwanted modes of oscillation are eliminated, an external output iris means for coupling energy outwardly of said external resonator, and external resonator output iris capacitive loading means associated with said iris means for tuning the pass band of said external output iris means whereby the energy coupling to the load may be varied as desired and broad banding may be achieved.

11. In an electron tube apparatus employing an internal cavity resonator interacting with a beam of charged particles, an iris opening in the side wall of the internal cavity resonator, a wave energy permeable material sealed over said iris opening and forming a vacuum-tight closure, a rectangular external cavity resonator mounted adjacent said internal cavity resonator and communicating with said internal resonator through said iris opening, a window loading member mounted adjacent said iris opening, and a lossy resonant mode suppression member protruding inwardly of said rectangular external cavity resonator in close proximity to said window loading member, said mode suppression member extending into said rectangular external cavity resonator from the short side walls thereof and being substantially perpendicular to the short side walls, whereby unwanted modes of oscillation are coupled to said lossy mode suppression member and thereby effectively suppressed.

12. In an apparatus as claimed in claim 11 wherein said lossy resonant mode suppression member comprises a threaded post screwed into the cavity resonator through a threaded aperture in the short side walls of said rectangular external cavity resonator.

13. In a reflex klystron oscillator apparatus having an internal cavity resonator arranged for interaction with a beam of electrons passable therethrough, the internal cavity resonator having an iris opening in the side wall thereof, a wave energy permeable material sealed over the iris opening and forming a vacuum-tight closure, a rectangular external cavity resonator mounted adjacent the internal cavity resonator and communicating with the internal resonator through the iris opening, a lossy resonant mode suppression member protruding inwardly of said rectangular external cavity resonator, said lossy mode suppression member forming a series resonant shunt at substantially the resonant frequency of the $\lambda/2$ mode of oscillation where λ is the wavelength of the desired resonant frequency of the klystron oscillator, said mode suppression member positioned within said external cavity resonator in substantial parallelism with and in a region of strong electric field of the $\lambda/2$ mode, whereby the $\lambda/2$ mode is heavily attenuated and effectively suppressed.

14. In an apparatus as claimed in claim 13 including a second lossy mode suppression member protruding inwardly of said rectangular external cavity resonator, said second mode suppression member forming a series resonant shunt at substantially the resonant frequency of the $3\lambda/2$ mode of oscillation, said second mode suppression member positioned within said external cavity resonator in substantial parallelism with and in a region of strong electric field of the $3\lambda/2$ mode, whereby the $3\lambda/2$ mode is heavily attenuated and effectively suppressed.

15. In an apparatus as claimed in claim 14 wherein said lossy mode suppression members comprise threaded lossy probe members screwed into said rectangular external cavity resonator through threaded side wall portions thereof.

References Cited in the file of this patent

UNITED STATES PATENTS

2,424,576	Mason	July 29, 1947
2,524,175	Preist	Oct. 3, 1950
2,538,560	Findlay	Jan. 16, 1951
2,575,383	Field	Nov. 20, 1951
2,601,539	Marcum	June 24, 1952
2,602,148	Pierce	July 1, 1952
2,658,147	Bainbridge	Nov. 3, 1953
2,789,250	Varian et al.	Apr. 16, 1957
2,798,184	Gardner et al.	July 2, 1957
2,806,972	Sensiper	Sept. 17, 1957