Dec. 28, 1948. A. E. ANDERSON 2,457,194

MICROWAVE OSCILLATOR

Filed June 23, 1943 2 Sheets-Sheet 1

FIG. 1

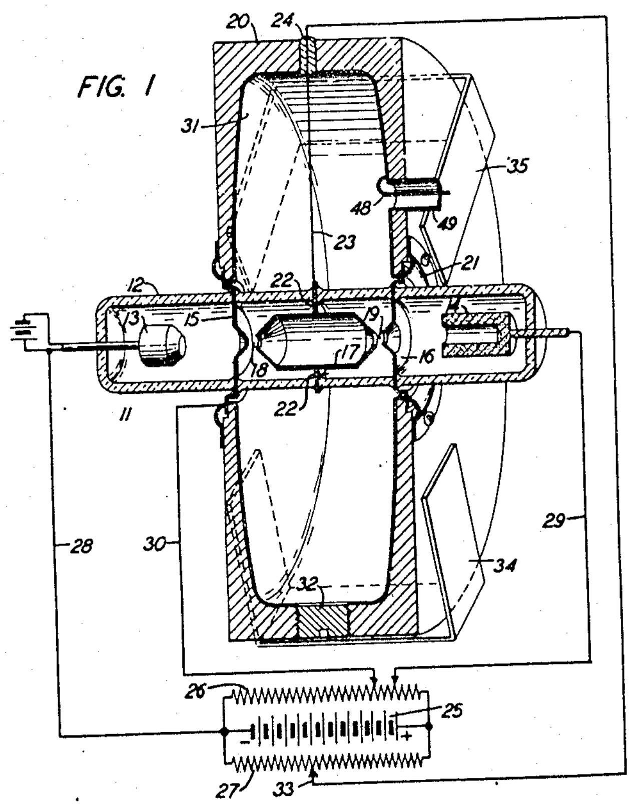
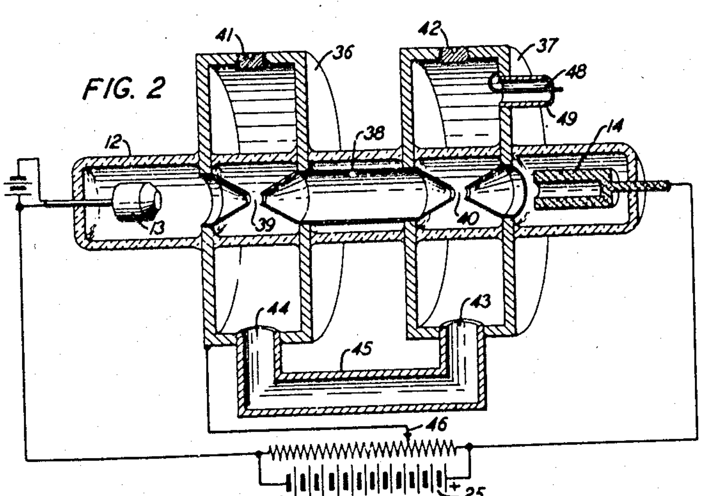


FIG. 2



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2 Sheets-Sheet 2

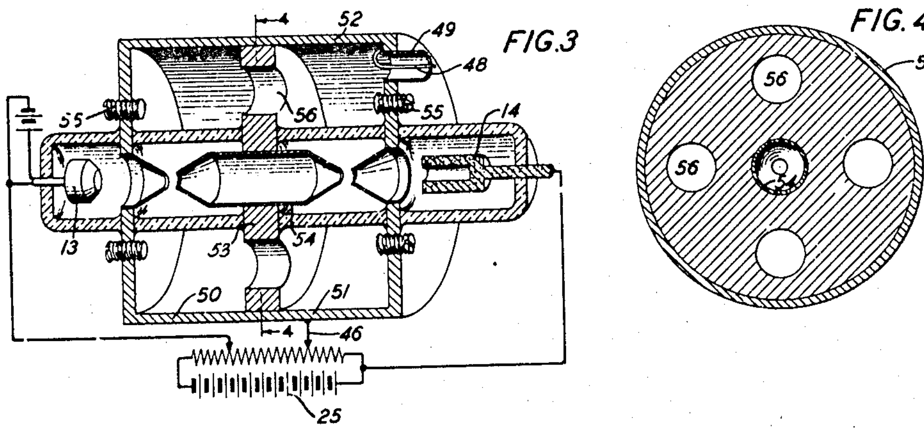

FIG. 3

FIG. 4

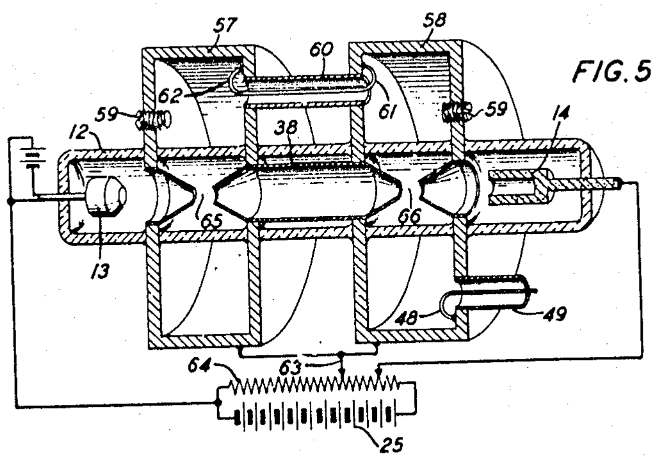

FIG. 5

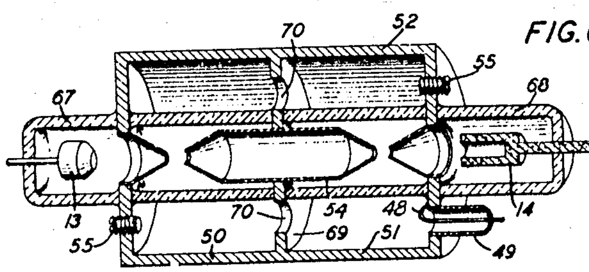

FIG. 6

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Patented Dec. 28, 1948 2,457,194

UNITED STATES PATENT OFFICE

2,457,194

MICROWAVE OSCILLATOR

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Application June 23, 1943, Serial No. 491,961

5 Claims. (Cl. 315—6)

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This invention relates to microwave oscillators and more particularly to oscillation-producing systems utilizing electron velocity variation apparatus and resonant chambers for producing oscillations in the centimeter wavelength range.

Resonant chambers or cavities, as they are commonly termed, have many advantages for use in oscillators in the microwave art. However, at extreme frequencies they become physically so small that their structure is difficult to design and manufacture. Moreover, slight variations from the ideal result in comparatively large deviations in resonance frequency. The necessity for tuning appliances to adjust small resonance cavities to the desired frequency increases these difficulties. Inasmuch as these conductive cavities or chambers are multi-frequency resonators, it is possible to resort to oscillations of one of the higher frequency modes. In this case the gravest frequency oscillations, that is, the lowest natural frequency mode oscillation which the conductive cavity will support, may preponderate to such an extent as to dissipate most of the input energy and may cause heating and other undesirable interaction effects.

A principal object of the invention is to enable an oscillator employing resonant cavities to operate at one of the higher modes free from the disturbance and loss attendant upon oscillation at a graver mode.

Another object of the invention is to inhibit the operation of a cavity resonator at its gravest frequency while permitting it to operate freely at a frequency of a higher mode.

In accordance with the invention a microwave oscillator utilizing one or more resonant chambers is operated at a frequency higher than that of the gravest mode which any of the chambers will support. To avoid the energy losses and other undesirable characteristics attending concomitant production of oscillations of the gravest mode such grave mode oscillations are inhibited. This may be effected by any of several expedients used singly or together.

One expedient for suppressing oscillations of the gravest mode relates to choice of the impelling electromotive force applied between the electron source and the collector of the principal electron beam. If the magnitude of that electromotive force be so chosen that the transit time for the drift space between the velocity variation gap and the energy derivation gap is correct for a higher mode oscillation but is not correct for the gravest mode of oscillation, oscillations of the higher frequency will be sustained but

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those of the gravest mode will be inhibited. In some instances it may be desirable to inhibit several of the graver modes of oscillation and by suitable choice of the electromotive force this may be done.

An alternative expedient is the use of a feedback path, the path being so designed that its frequency transmission range permits only oscillations of higher than the gravest mode or of higher than a few of the graver modes to freely pass.

A feature of the invention is the use of a variable magnetic field to focus the electron beam at a chosen point in its course. This is effected by a permanent magnet structure which comprises the resonant chamber itself. Variable magnetic shunts enable the magnetic field strength to which the beam is subjected to be varied as desired.

In the drawing Fig. 1 illustrates diagrammatically a microwave oscillator of the single resonance chamber type in which oscillations of the gravest mode are inhibited by selection of the electron impelling electromotive force.

Fig. 2 illustrates in similar manner a two-resonator oscillator with a wave guide feedback path which inhibits oscillations of the gravest mode.

Fig. 3 is a modification of the disclosure of Fig. 2 in which the feedback comprises a plurality of internal wave guides.

Fig. 4 is a cross-section along the line 4—4 of Fig. 3.

Fig. 5 shows a two-chamber oscillator in which selection of a higher order mode of oscillation and inhibition of the gravest mode is effected by choice of the electron impelling electromotive force.

Fig. 6 is a modification of the disclosure of Fig. 3 in which the internal wave guides are replaced by aperture or iris couplings.

Referring to Fig. 1, an electron discharge device 11 comprises an evacuated container 12 of dielectric material enclosing an electron gun 13 of any suitable type and a cup-shaped electron collector 14 which may be of graphite or other appropriate material. Sealed through the walls of the container 12 are the conducting discs 15 and 16 each apertured at the center as indicated to permit the passage of a beam of electrons therethrough from the gun 13 to the collector 14. Between the discs 15 and 16 is a cylindrical conducting member 17 with end apertures aligned with the apertures in the discs 15 and 16 to form so-called gaps 18 and 19. The member 17 provides a substantially field-free drift space of well-known type between the gaps 18 and 19. Surrounding the container 12 and constituting with the discs 15 and 16 an enclosing resonant cavity is the two-part shell 20 consisting of permanent magnetic material. For this purpose any suitable permanent magnetic material may be used as, for example, the alloy disclosed in the patent to Jonas 2,295,082, September 8, 1942. The magnetic material of the cavity resonator shell may be permanently magnetized with the central portion immediately adjacent the outer periphery of disc 15 polarized as a positive magnetic pole and the central portion adjacent the outer periphery of disc 16 polarized as a negative magnetic pole or with the reverse magnetization, as desired. The shell 20 may preferably be divided along a diametrical plane passing through the longitudinal axis of container 12 to permit ready assembly. Clamps 21 serve to hold the inwardly projecting rims of discs 15 and 16 in close engagement with the surface of the shell 20 and to close any apertures therebetween from an electromagnetic standpoint. The drift space member 17 is supported by metallic rods 22 each attached to the member 17 at one end and anchored at the opposite end in the wall of the insulating container 12. A lead 23 passing through an insulating bead 24 in the shell 20 serves to electrically connect the member 17 to an external circuit.

A source of electromotive force 25 provided with potentiometers 26 and 27 may serve to apply the customary polarizing potentials to the electron gun 13, electron collector 14, and the resonant cavity over leads 28, 29 and 30, respectively. As is well understood in this art, a beam of electrons proceeding from the gun 13 is subjected at the gap 18 to the electromagnetic field of the resonant chamber to cause the velocities of the passing electrons to be varied in accordance with the instantaneous magnitude of the electric field at that point. At the gap 19, after transit across the drift space the electrons will have become bunched so that the stream is charge density varied. The density varied electron stream reacts with the electromagnetic field of the resonant chamber to yield energy thereto in a manner well known in this art. Accordingly, the apparatus serves to produce oscillations of frequencies determined principally by the resonance characteristics of the resonance chamber. In order to produce sustained oscillations it is essential that the groups or bunches of electrons arriving at the gap 19 reach it at such times, that on the whole they will deliver more energy to the electromagnetic field than they abstract from it. It transpires, therefore, that with a given electromotive force impressed by the source 25 between the electron source 13 and the collector 14 and with given potentials impressed upon the discs 15 and 16 and upon the drift space member 17, the transit time required for electrons to pass from the gap 18 through member 17 to the gap 19 may be such as to bring the electrons to the gap 19 at a time favorable for oscillations of one frequency but not for oscillations of a different frequency. Applicant has found that with a particular apparatus beginning with an electromotive force of 500 volts applied between source 13 and collector 14 and gradually increasing that electromotive force that at 800 volts oscillations of 20 centimeters wavelength corresponding to the gravest mode of oscillation of the resonant cavity were obtained. Calculations showed that the drift time between the velocity varying gap and the energy extraction gap was approximately 1.75 cycles. As the voltage was increased the oscillations disappeared until at a point in excess of 1000 volts oscillations of 10.25 centimeters corresponding to a higher order resonance mode of the resonant cavity were obtained. Further increase in voltage caused the oscillations of 10.25 centimeters wavelength to be suppressed and at a point below 2500 volts oscillations of 7.65 centimeters wavelength were obtained. The invention, therefore, enables very short waves to be produced with a device of such physical dimensions as to lend itself readily to manufacture.

It is highly important in the generation of very short waves to be able to make some variation in the frequency in order to compensate for variations in manufacture of apparatus and to permit a system to be tuned to any desired standard. With apparatus of extremely small magnitude this is a most difficult matter since any attempt to vary the dimensions or volume of the resonant chamber is attended with problems of variable mechanisms which must be accommodated in extremely limited space. Moreover, any variation whatever in the volume of a very small resonant chamber is likely to make an enormous absolute frequency change in the resonance frequency. The apparatus of the invention overcomes this difficulty in that it is of sufficient magnitude to enable customary tuning appliances to be utilized and the amount by which they change the resonance frequencies of the chamber may readily be made comparatively small. In the apparatus of Fig. 1 reliance for tuning is had primarily upon one or more tuning plugs 32 of well-known type. It has been explained that selection of a desired higher resonance frequency and suppression of a graver mode of oscillation may be had by the proper choice of impelling electromotive force applied between electron source 13 and collector 14. Let us assume that the mean velocity of electrons in their transit time between gaps 18 and 19 is a function of the electromotive force applied to the collector 14. Actually, the situation is by no means that simple although the principle is not affected. In the absence of an alternating electromagnetic field within the resonant chamber electrons leaving the source 13 are accelerated as they approach the disc 15 and, accordingly, enter the gap 18 with a velocity substantially determined by the potential of the disc 15. If the transit chamber 17 be maintained at the same steady potential as the disc 15 electrons will continue in their transit across the gap 18 through the drift space and across the gap 19 with substantially constant velocity and without further acceleration since disc 16 is at the same potential as disc 15. The electron velocity, under such circumstances, would therefore be determined chiefly by the position of the variable tap of the lead 30 on the potentiometer 26. However, the transit time will be different from that assumed if the position of the tap 33 upon potentiometer 27 be such as to impress upon the drift space chamber 17 a potential different from that of the discs 15 and 16. As disclosed herein the potential of chamber 17 is somewht lower than that of the discs. Consequently, electrons in their transit across gap 18 will experience a reduction in velocity and will proceed thereafter through the drift space at the reduced velocity until they reach the gap 19 across which they will be accelerated up to the velocity with which they entered gap 18. This will have the effect of increasing the transit time. Conversely, positioning the tap 33 to impress upon chamber 17 a potential higher than that of discs 15 and 16 will result in decreasing the transit time within the drift space.

As is well known the tendency of an electron beam after leaving the cathode or electron gun is to diverge. If this occurs to an undesirable extent a large portion of the beam may be so spread out as not to pass through the aligned apertures and thus to be intercepted before doing useful work at the gap 19. In order to prevent such a divergence, it is a customary practice in this art to apply a concentrating or collimating magnetic field. Preferably, the field should be of such strength as to enable substantially all of the electrons to traverse the gap 19. The reaction between electrons and the electromagnetic field in their transit across the gap is enhanced if the electron passes very close to the margins of the gap apertures or, in other words, to the perimeter of the circular openings at the extremities of the gaps.

A certain degree of focussing is desirable and may be obtained by use of a magnetic field. According to one feature of this invention, the magnetic field is produced by the shell 20 of the cavity itself which consists of permanently magnetized material. In order to vary the strength of the magnetic field applied across the gap, a plurality of external shunts comprising U-shaped strips 34 and 35 of soft magnetic iron material, the free ends of which closely engage the external walls of the shell 20 may be employed. As these are moved inwardly toward the dielectric container 12 they tend to divert the magnetic field from the gaps. As they are drawn outwardly they permit increase of that field.

The resonance characteristic of a closed chamber of conducting material depends to a considerable extent upon the nature and conductivity of its interior surface. In order to maintain energy loss in the chamber at as low a point as possible it is desirable that the interior surface have a very high conductivity. Moreover, in the case of a shell of magnetic material it is desirable to interpose a conducting screen between the internal electromagnetic field and the magnetic material in order to reduce hysteresis loss at the surface of the material. Accordingly, a coating or plating 31 of highly conducting material such as copper or copper overplated with silver may be provided. The internal surface and a portion of the circular periphery of tuning plugs 32 may be likewise plated for the same purpose.

Fig. 2 discloses an oscillation-producing apparatus in which the electron source, the electron collector and the polarizing source are designated as in Fig. 1. Positioned with their apertures in alignment with the electron beam passing from source 13 to collector 14 are two toroidal cavity resonators 36 and 37 physically connected by a tubular conducting member 38 which encloses the drift space between gaps 39 and 40. A plurality of tuning plugs 41, 42, similar to plug 32 of Fig. 1 may be provided for each of the chambers 36 and 37. Connecting the chamber 37 to the chamber 36 and coupled to each of these chambers by predesigned aperture or iris openings 43 and 44 is a wave guide 45. The coupling irises and the wave guide are given such dimensions as to freely pass oscillations of a frequency corresponding to a desired higher order resonance of the chambers 36 and 37 but to suppress oscillations of the gravest resonance mode of these two chambers. Variable tap 46 enables the polarizing potential applied to the chambers 36 and 37 and to the drift chamber 38 to be appropriately selected. In operation the electron beam passing gap 39 is subjected to a velocity variation after which, in the course of transit through the drift space of chamber 38, it becomes charge density varied so that at gap 40 it may react with the electromagnetic field within chamber 37 to yield energy thereto. Oscillations of a desired frequency higher than that of the gravest resonance mode are fed back by the wave guide 45 which precludes feedback of the graver mode oscillations. In this manner, sustained oscillations of the desired frequency are produced. Energy of the desired oscillation frequency may be withdrawn from the resonant output chamber 37 by an output coupling loop 48 and a coaxial output circuit 49 as in the case of Fig. 1.

Fig. 3 discloses a modification of the apparatus of Fig. 2 in which the velocity varying chamber 50 and the output energy chamber 51 are wholly constituted by a cylindrical shell 52 divided into two portions by a thick walled disc 53 of conducting material which supports at its center a drift space member 54. Each of the chambers is provided with a plurality of tuning plugs 55. A plurality of tubular openings 56 as indicated in Figs. 3 and 4 pass through the disc 53 and serve as wave guides to feed back energy from resonance chamber 51 to chamber 50. These wave guides may be designed in a manner similar to the wave guide 45 of Fig. 2 to freely permit passage of oscillations of a desired higher order resonance mode and to preclude feedback of oscillations of the gravest resonance mode of either chamber. It will be understood that, as in the case of Fig. 2, the two chambers may be tuned to have substantially the same resonance characteristics by means of the tuning plugs 55.

Fig. 5 discloses an oscillating system in which two resonance chambers 57 and 58 may be substantially identical in design with the resonance chambers 36 and 37 of Fig. 2. The tuning plugs 59 are in this instance shown at the ends of these structures rather than at their outer peripheries as in Fig. 2. A coaxial feedback line 60 having terminal coupling coils 61 and 62 serves to feed back output energy from chamber 58 to velocity varying chamber 57. In this structure the coaxial line 60 may be designed to transmit oscillations of the entire gamut of resonance frequencies of the two resonance chambers. In order to selectively sustain oscillations of a frequency corresponding to a higher order of resonance mode of the chambers 57 and 58, and, at the same time, inhibit oscillations of one or more of the gravest modes of oscillation, the variable contactor 63 of potentiometer 64 may be positioned in accordance with the principle presented in detail in the discussion of Fig. 1 to predetermine the transit time of electrons traversing the drift space within tube 38 between gaps 65 and 66 so that oscillations of the gravest mode will not be sustained but oscillations of the desired higher order frequency mode will be sustained.

Fig. 6, like Fig. 3, comprises a central metallic shell 52 divided into two resonance chambers 50 and 51 respectively. At the ends of the shell insulating container portions 67 and 68 enclose the electron gun 13 and the electron collector 14, respectively. In lieu of the thick-walled disc 53 of Fig. 3, a thin-walled disc 69 is utilized. In this disc are apertures or irises 70 which correspond in function to the wave guides 56 of Fig. 3. The manner of design of such irises or apertures to permit transmission therethrough of oscillations of a desired frequency while, at the same time, precluding transmission of oscillations of substantially lower frequency is well understood in the art. Accordingly, the aperture 70 will be designed to transmit the desired higher order resonance frequency and to suppress transmission of one or more of the graver mode frequencies. Each of the resonator chambers disclosed in the various figures of the drawing may have its interior coated with low resistance material as in the case of Fig. 1. Moreover each of the resonator chambers may consist of permanently magnetized magnetic material to assist in collimation of the electron beam.

The electron source 13 which has been referred to variously as a source or a gun may be of any well-known type as may also the electron collector 14.

It will be apparent that the invention greatly simplifies the design of oscillators of the velocity variation type at extremely high frequencies. It will also be apparent that it enables a nice control or adjustment of the operating frequency of such devices to be had.

What is claimed is:

1. An oscillator comprising an electron beam apparatus including a source of an electron beam, a cavity resonator having a gap adjacent the path of the beam to vary the electron velocities in the beam, a second cavity resonator having a gap adjacent the path of the beam at a point of density variation therein to receive energy from the beam, said resonators having their gravest mode of operation at substantially the same frequency and means coupling the second resonator to the first for feeding back energy thereto, said coupling means having a transmission frequency range which is limited to frequencies considerably above the frequency of the gravest mode whereby oscillations of a higher mode are produced and oscillations of the gravest mode are inhibited.

2. A microwave source comprising an electron discharge device including an electron gun, an anode, a source of electromotive force connected therebetween, a pair of cavity resonators each having an aperture adjacent the path of the beam of electrons which proceeds from the gun to the anode whereby the electromotive force of the field of the first of said resonators serves to vary the velocities of passing electrons and the electromotive force of the second of said resonators reacts with the passing electron beam to derive energy therefrom, means coupling said resonators together, said coupling means having a transmission frequency range which lies entirely above the gravest frequency mode of either resonator whereby only oscillations of a higher mode may be produced and one of said resonators having means connected therewith for tuning the resonator to enable it to operate at high efficiency at the same frequency as the other resonator.

3. An electron discharge device comprising two toroidal cavity resonators of conducting material, each resonator having a central opening passing therethrough and a circular aperture through which an internal electromagnetic field may extend across the opening, means holding said resonators in fixed position with respect to each other with their central openings aligned, an electron gun and a collector electrode connected to the resonators to pass an electron beam through the aligned central apertures, a plurality of conducting tubes extending between the resonators and opening into each resonator whereby oscillation energy may be transmitted from one resonator to the other, the tubes each having a critical frequency slightly higher than the frequency of the gravest mode of either resonator whereby the transmission of oscillation energy of the gravest mode of either resonator is precluded.

4. An electron velocity variation device comprising a source of electrons, an electron collector and an electrical resonant system connected thereto comprising an external hollow cylinder of conducting material, an internal hollow cylinder of conducting material fixed in coaxial position within the external cylinder by an annular wall of conducting material which divides the external cylinder longitudinally into two cavity resonators, the ends of both the external and the internal cylinder being apertured at points aligned with the path of the electron beam passing from the electron source to the electron collector, and coupling means between said two cavity resonators comprising an opening in the annular wall having a cut-off frequency above the frequency of the gravest mode of oscillation of either cavity resonator but less than the frequency of the mode in which oscillation is desired.

5. An electron discharge device comprising an electron gun, an anode, a source of electromotive force connected therebetween, means forming two cavity resonators longitudinally spaced between said electron gun and said anode each resonator having an aperture adjacent the path of the beam of electrons which proceeds from the gun to the anode, coupling means between said resonators having a high-pass transmission characteristic to prevent oscillation at the gravest mode of the said c ity resonators, and means for reducing the cross-sectional area of the beam of electrons in the region of the apertures, comprising permanent magnets for producing a focussing field in the region of said apertures.

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