Jan. 6, 1970 H. G. OLTMAN, JR 3,488,550

HIGH POWER RESONANT CAVITY TUBE

Filed July 11, 1967 2 Sheets-Sheet 1

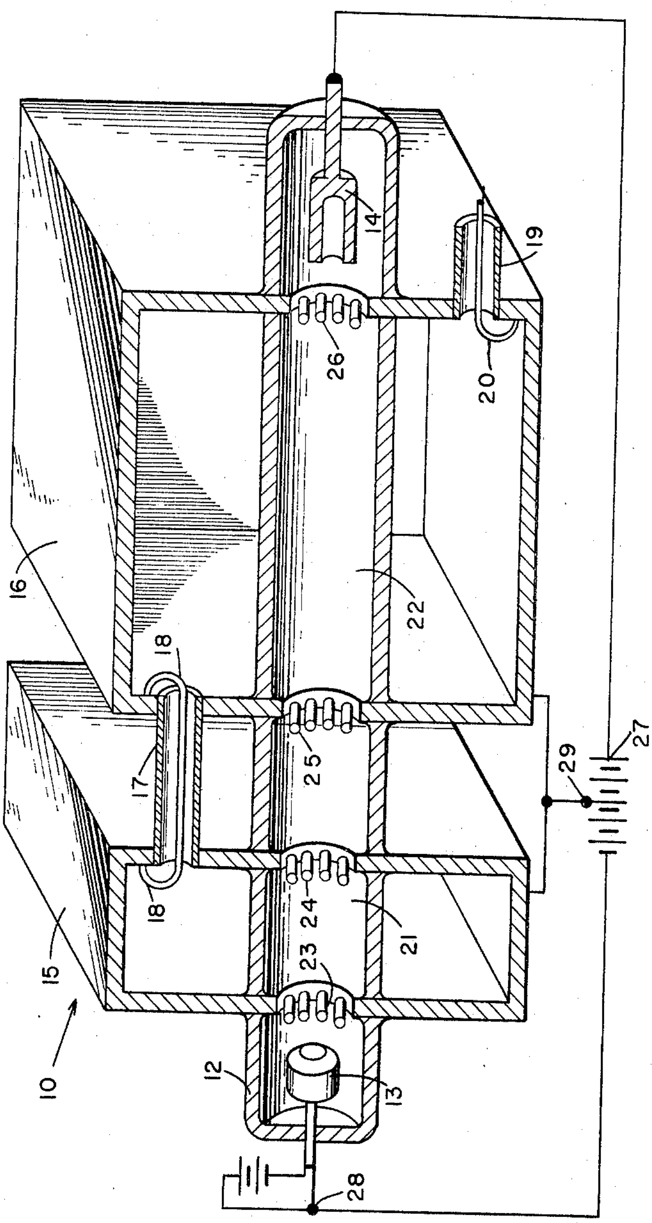

Fig. 1

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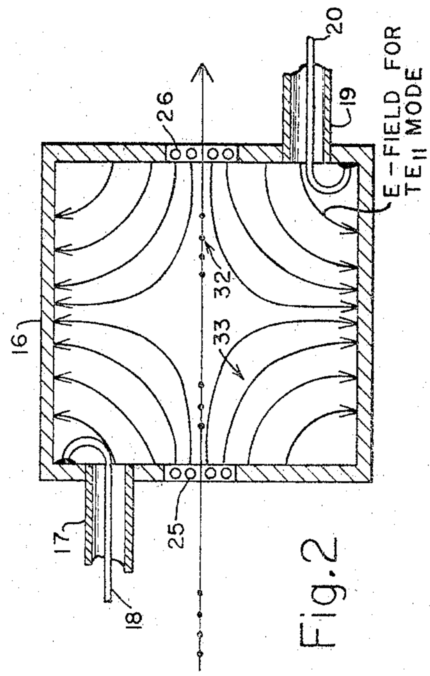

Fig. 2

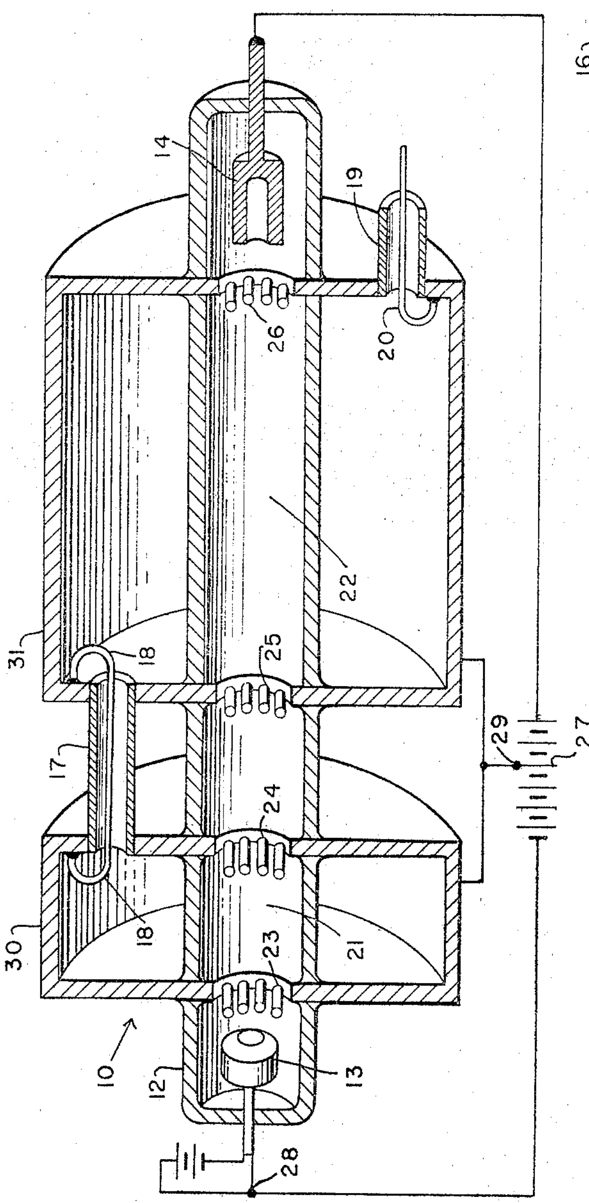

Fig. 3

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HIGH POWER RESONANT CAVITY TUBE

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ABSTRACT OF THE DISCLOSURE

A cavity resonator is operated in the TE_{110} mode and is associated with an electron stream so as to enable the electromagnetic field of the cavity resonator to act upon the electron stream for a longer period of time than heretofore available in prior art devices.

BACKGROUND OF THE INVENTION

This invention pertains to the field of cavity resonators and, more particularly, the invention is cencerned with an improved cavity resonator for increasing the interaction of the resonator with an electron stream. Various devices exist in the prior art for coupling cavity resonators to an electron stream so as to induce a current or density variation in the electron stream by accelerating and decelerating, which results in bunching the electrons as a function of the resonant frequency of the cavity resonator. One such device is disclosed in U.S. Patent No. 2,379,818, entitled "Coupling Between Resonators and Electron Streams" by Warren B. Mason. In that patent, there is disclosed a two-cavity resonator klystron in which the impedance of the cavity is matched to the electron beam in order to achieve improved operation. A limitation exists for this type of device when operated at millimeter wave lengths in that the spacing beween the cones is so close that the probability of arcing is increased, and this in turn limits the power level at which the device can be operated. Machining becomes critical for re-entrant cones in millimeter wavelength devices because of the small size of components. It would therefore be advantageous to have a device wherein a larger physical cavity resonator achieves the same or greater energy interaction with the electron stream.

SUMMARY OF THE INVENTION

In a preferred embodiment of the invention, it is possible to increase the interaction energy between the resonant cavity and the electron stream by increasing the physical length of the cavity and allowing the cavity to operate in the TE_{110} mode for a rectangular or square cavity and a TM_{010} mode for a circular cavity. The modes of resonant cavities and waveguides designate the distribution of the electric and magnetic fields. For example, the symbol TE indicates that the electric field is everywhere transverse to the axis of the transmission line or resonator. For the designation TE_{mn}, the subscript m denotes the number of maxima of electric field along the wide dimension of a rectangular waveguide, or in a resonator its equal to its length. The subscript n denotes the number of maxima of electric field along the narrow dimension. The mode TE_{110} therefore has one maxima along the length and another along the width. In the time domain this mode, for a period of one cycle, generates an electric field along the long dimension of the cavity which increases from zero to a maximum, then back to zero, increasing to a maximum in the reverse direction and ends the cycle by decreasing to zero. An electron entering the resonant cavity along the axial center at a time near the beginning of the cycle and exiting the cavity at a time near the end of the cycle will be positioned at all times

during the cycle to do work on the field. The interaction time of this device will be one cycle instead of one-half cycle or less, obtainable in prior art devices. The power generated by this improved cavity can be four times more than that available from conventionally operated cavities fabricated, using the same materials. An indirect advantage is gained by the use of a large cavity in that fabrication problems are simplified, which is particularly important at millimeter wavelengths.

Accordingly, it is an object of the present invention to provide an improved resonant cavity for interaction with an electron stream.

It is a further object of the present invention to provide an apparatus capable of interacting with an electron stream for a longer period of time.

It is another object of the present invention to provide a resonant cavity which can minimize fabrication problems.

The aforementioned and other objects of the present invention will become more apparent when taken in conjunction with the following description and drawings, throughout which like characters indicate like parts, and which drawings form a part of this application.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 illustrates diagrammatically a microwave oscillator of the dual resonance chamber type utilizing a rectangular and square type resonant cavity in accordance with the invention;

FIGURE 2 illustrates the distributed electric field in the square resonant cavity illustrated in FIGURE 1; and

FIGURE 3 illustrates diagrammatically a microwave oscillator of the dual resonance chamber type utilizing cylindrical resonant cavities in accordance with the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGURE 1 shows a two-cavity oscillator **10** associated with the cavity resonator **16**. This showing is typical only as the resonant cavity of this invention may be associated with different types of electron tubes and circuits. The oscillator **10** has an evacuated container **12** of dielectric material enclosing an electron gun **13** and a collector **14**. Passing through the wall of the container **12** are the disc-like walls of conducting resonant cavities **15** and **16**. Apertured openings pass through the center of each of the disc-like walls of resonant cavities **15** and **16** and inserted into these openings are conductive grids **23**, **24** and **25**, **26**, respectively. These grids increase the interaction of the field with the stream. The openings permit an electron stream to pass from the electron gun **13** through to the collector **14** with a minimum amount of hindrance. A coaxial feedback line **17** having a coupling loop **18** at both ends serves to feed back output energy from resonant cavity **16** to resonant cavity **15**. Energy of the desired oscillation frequency may be withdrawn from resonant cavity **16** by an output coaxial line **19** having a coupling loop **20** projecting into the cavity. The resonant cavity **16** is approximately twice as long as resonant cavity **15**. FIGURE 1 also illustrates the difference between the physical size of a rectangular cavity which is operated in the TE_{10} mode (cavity **15**) as versus a square cavity operated in the TE_{110} mode (cavity **16**). The increased length enables a longer interaction time upon the electron stream which passes through the openings in the disc-like walls of the resonant cavity.

A potential source **27** is connected between the electron gun **13** and the electron collector **14** so as to provide the necessary operating potentials. A tap **29** connected to the power source **27** provides a polarizing potential to the resonant cavities **15** and **16**. A filament supply **30** provides the electron gun **13** with the necessary potential for heating the filament. In operation, the electron stream flows from the electron gun **13** to the collector **14** and thereby passes through gaps **21** and **22** in resonators **15** and **16**, respectively. The electron stream in passing gap **21** is subjected to a velocity variation which, in the course of transit through to the gap **22**, becomes bunched so that at gap **22**, it may react with the electromagnetic field within resonant cavity **16** to yield energy thereto. Oscillations of a desired frequency are fed back by the coaxial cable **17** to the resonant cavity **15**. This enables oscillations of the desired frequency to be sustained. Energy of the desired oscillation frequency may be withdrawn from cavity **16** by use of the output coaxial cable **19** and coupling loop **20**. Also, in order to sustain oscillations, it is essential that the groups or bunches of electrons arising at gap **22** reach it at such times that on the whole, they will deliver more energy to the electromagnetic field than they extract from it. The electromagnetic waves in the interior of the cavity resonator periodically establishes a high potential difference between the grids **23** and **24**, alternating in polarity at the frequency of the electromagnetic waves. During the portion of the frequency cycle when grid **24** is positive with respect to grid **23**, the electromagnetic field produced by the grid is of such polarity as to aid the motion of the electrons from the electron gun **13** toward the collector **14**. The electrons situated between grids 23 and 24 are accelerated by the field produced by the cavity resonator **15** and kinetic energy is stored in these electrons. The accelerated electrons begin to gain upon those ahead and thus tend to create a non-uniform density of electrons in the electron stream.

During the portion of the frequency cycle, when grid **24** is negative with respect to grid **23**, the field produced by the resonator is in such a direction as to oppose the electron motion, thus slowing them down with the result that the field absorbs energy from the electrons. This cycle of operation has assumed that those electrons that have been accelerated by the difference in potential between the grids have already passed through the cavity area and are in the space between grids **24** and **25**. If, for some reason, these electrons have not yet passed completely through the cavity, when the field reverses, work will be done upon these electrons, negating the acceleration imparted to the electrons in the first half cycle. Assuming that the electrons within the grid area (that is, the area beween grids **23** and **24**) are those that have had no work done upon them as yet, then when the field's potential reverses, the field will then tend to oppose their motion, thus slowing these electrons down with the result that the field absorbs energy from the electrons. The electrons slowed down are gained upon by the next group of accelerated electrons, resulting in a tendency to group a bunch of the electrons. The energy which the field of the resonator delivers to the electrons by accelerating them during one-half cycle is returned to the field during the succeeding half cycle when other electrons are slowed down by the field. In resonant cavity **16**, operated in the TE_{110} mode, there exists one complete cycle of electromagnetic waves or, in other words, one complete potential difference, that is, we may think of the resonant cavity as having at approximately the halfway point an additional grid with respect to which if the potential between the grid **25** and the central grid is rising toward the maximum, then the potential between the central grid and the grid **26** is heading or decreasing toward a corresponding negative maximum. As the electron bunch enters this cavity past the grid **25**, it generates electromagnetic waves in the cavity or does work in the cavity for the entire transition time between grids **25** and **26**. This is accomplished due to the fact that when the electron bunch passes this imaginary central grid the cycle, that is, the potential of polarity between the central grid and grid **26**, reverses such that it becomes identical to what was the potential between grids **25** and the central grid. The electron then interacts with the electro-

magnetic field of the cavity for a period that is approximately twice as long as that achievable in a TE_{10} mode.

For purposes of illustration, only the output cavity **16** was illustrated operating in the TE_{11} mode. It will be obvious to persons skilled in the art that the modulating cavity **15** also may be operated in the TE_{11} mode with a substantial increase in efficiency for the oscillator.

It will also be obvious to persons skilled in the art that amplifiers may also utilize this improved resonant cavity with success. For example, in the oscillator illustrated in FIGURE 1, energy is coupled back from the output cavity **16** to the modulating cavity **15**. In an amplifier system, this feedback loop can be eliminated and an input from a transmission line can be directly coupled to the resonant cavity **15** and the signal present on this transmission line would determine the modulation characteristics of the electron stream passing through the resonant cavity **15**. In this way, within a certain band width, the input signal could be amplified with more efficiency than would be possible in cavities operated in the TE_{10} mode.

Referring now to FIGURE 3, resonant cavities **15** and **16** have been replaced with corresponding cylindrical cavities **30** and **31**, respectively. The circular mode which corresponds to the rectangular mode TE_{110} is the TM_{011} and cavity **31** is dimensioned to support this mode for the frequency range of interest. The cylindrical cavity has the distinct advantage of being relatively simple to manufacture.

While there has been shown what are considered to be the preferred embodiments of the present invention, it will be manifest that many changes and modifications may be made therein without departing from the essential spirit of the invention. It is intended, therefore, in the annexed claims, to cover all such changes and modifications as fall within the true scope of the invention.

What is claimed is:

1. A high power resonant cavity tube comprising:

(a) a source of an electron stream having a predetermined velocity;

(b) means for modulating said electron stream; and

(c) a cavity resonator following said means for modulating and having a pair of spaced openings, said openings having a spacing related to the velocity of said electron stream so that said electrons pass through said resonator between said opening within one cycle of an electromagnetic wave excited within said resonator, said resonator having such a shape that said electromagnetic wave within said resonator has alternating fields varying in such a manner that an electron entering said cavity resonator at the beginning of a cycle is capable of delivering energy to said electromagnetic wave during its entire passage through said cavity.

2. A high power resonant cavity tube comprising:

(a) a source of an electron stream including means for accelerating said electrons to a predetermined average velocity;

(b) a first resonant cavity for velocity modulating said electrons; and

(c) a second cavity resonator operable in the TE_{110} mode, said second resonator having a pair of openings with a spacing so related to said average electron velocity that the electrons pass between said openings within one cycle of an electromagnetic wave generated in said second resonator, whereby a bunch of electrons entering the first one of said openings at the beginning of a cycle of said electromagnetic wave are capable of delivering energy to said second resonator during the entire cycle of said wave.

3. A cavity resonator as defined in claim **2** wherein said first and said second resonators are electromagnetically coupled, thereby to generate microwave oscillations.

4. A high power resonant cavity tube comprising:

(a) a source of an electron stream including means for imparting to said electrons a predetermined average velocity;

(b) a first cavity disposed to be transversed by said electron stream for velocity-modulating said electron stream;

(c) a second cavity resonator having a pair of spaced openings capable of operating in the TM_{011} mode, said openings being spaced such a distance related to the average velocity of said electrons that said electrons pass between said openings during one cycle of an electromagnetic wave excited in said second resonator, whereby an electron entering said second resonator at the beginning of a cycle of the electromagnetic wave is capable of delivering energy to said second resonator during the entire cycle of said electromagnetic wave.

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