PLASMA TUBE FOR MICROWAVE CIRCUITS

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FIG. 1

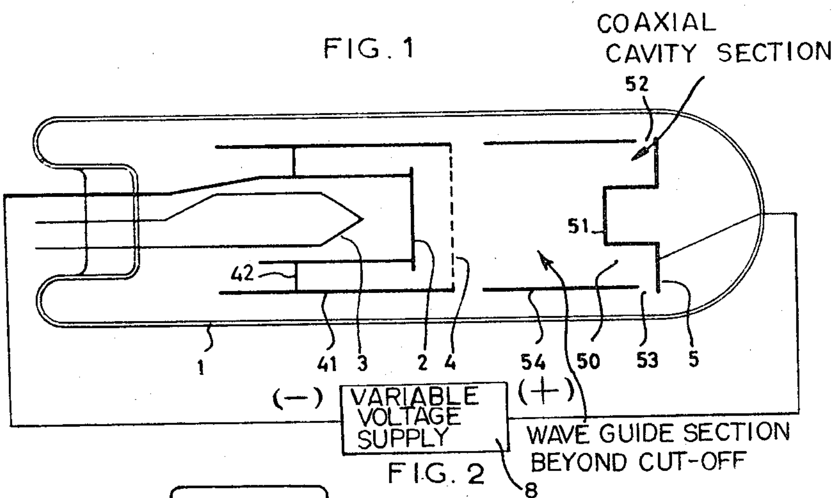
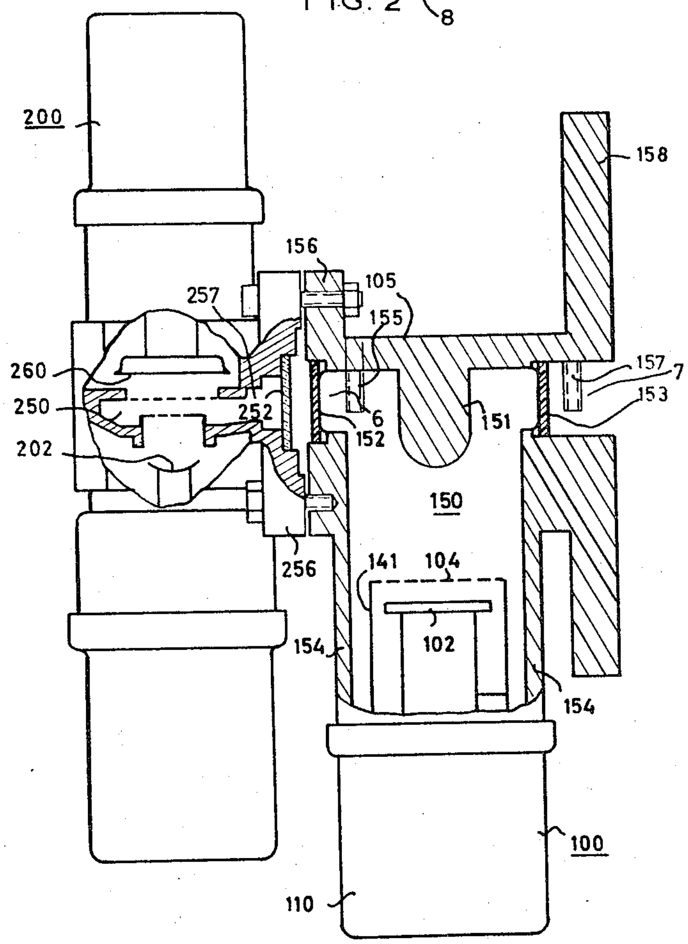


FIG. 2



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PLASMA TUBE FOR MICROWAVE CIRCUITS

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5 Claims. (Cl. 331—83)

This invention relates to a plasma tube adapted to be used as a component in microwave circuitry, particularly as a reactance cavity resonator for frequency modulating microwave electron tubes.

It is well known that in a discharge tube, a gas under low pressure, when used as a transmission medium for microwave signals, behaves as a dielectric medium whose dielectric constant is a function of the electron density, and therefore, a function of the discharge current. Thus the resonant frequency of a plasma cavity resonator can be controlled by varying the discharge current.

The simplest technique for producing a plasma consists in establishing a direct current discharge through a noble gas between a hot cathode and an anode. It is well known that plasmas thus produced exhibit important instabilities that can be detected by observing the spontaneous fluctuations of the voltage at the terminals of the tube. These fluctuations are associated with instabilities of the electron density of the plasma, thus making it impossible to utilize plasma tubes for cavity resonator frequency modulation.

It is known that plasma tube operation can be made stable and noiseless by restricting the ion generation region to the grid anode region of the tube. Discharge tube filled with a noble gas under low pressure, and in which the discharge is separated in two regions by a fine, relatively opaque grid placed between the hot oxide cathode and the anode, and in which the size of the grid openings, gas, gas pressure and over-all tube geometry are properly selected, have already been proposed by E. O. Johnson, J. Olmstead and W. M. Webster, in a paper entitled "The Tacitron, a Low Noise Thyratron Capable of Current Interruption by Grid Action" and published in the Proceedings of the I.R.E., vol. 42, No. 9, September 1954, pages 1350 to 1362. The grid potential in this case is the same as the cathode potential. Ionization take place solely in the region between the grid and anode, and the ions thus produced diffuse through the grid to form a cold plasma in the cathode region. This operating mode is called the anode glow mode, and has the advantage of producing a noiseless plasma as is required to control the resonant frequency of cavity resonators. The structure of the tube, however, does not allow for this kind of utilization due to the difficulties which would be encountered in preventing microwave energy from escaping in the cathode region of the plasma tube.

The object of the invention is to provide a plasma tube which can be used in a microwave circuit as a variable reactance or frequency modifying component.

A further object of the invention is to provide plasma tube means adapted to modulate cavity resonator oscillator tubes.

The plasma tube according to the invention consists of an electron discharge tube having a cathode, a grid and an anode, filled with a noble gas under low pressure, operating in the anode glow mode, whose anode forms a reentrant cavity resonator extending up to the proximity of the grid, the outer wall of the cavity forming a waveguide section beyond cut-off for all the frequencies of the frequency range of the tube. Consequently when the gas is not ionized, the cavity resonator does not vibrate in the usual reentrant cavity mode but as a quarter wave coaxial cavity closed at one end and

open in the transverse plane passing through the end of its ridged portion, microwave energy being prevented from escaping the coaxial cavity by means of the guide section beyond cut-off.

The diameter of a coaxial cavity resonator being, for a given frequency of the wave resonating within the cavity, smaller than the diameter of cylindrical cavity resonators, the outer wall of the coaxial cavity resonator can be given a diameter equal to that of the circular guide stub beyond cut-off. Thus the walls of the cylindrical portion and of the coaxial portion of the plasma tube can be made flush with each other. It results that the electron density of the plasma can be made larger and more uniform in the volume of the coaxial cavity than in prior art cavities and can allow a larger resonant frequency variation without lowering the Q of the cavity. Further the absorption of microwave energy due to the conductivity of the plasma is, for a given gas pressure and frequency variation, inversely related to the uniformity of the electron density of the plasma in the cavity.

According to the invention, the length of the coaxial cavity between its end wall and the plane passing through the end of the ridged portion is substantially a quarter of the resonant wavelength of the cavity when the discharge current in the same is zero.

Finally one knows from U.S. Patent No. 3,076,917 issued February 5, 1963, an electron tuning device for klystron tubes in which the resonant frequency of the cavity resonator of a reflex klystron is varied by coupling the said cavity resonator to the cavity resonator of a plasma tube and varying the discharge current across the plasma tube. The operation of this device is disturbed by the noise of the plasma tube and it is a further object of the invention to provide coupling arrangements of cavity resonator oscillator tubes and noiseless cavity resonator plasma tubes so as to obtain frequency modulated microwave electron discharge tubes.

Further objects and features will become apparent to those skilled in the art upon consideration of the following description read in connection with the drawing wherein:

FIG. 1 is a schematic representation of a variable reactance plasma tube according to the invention; and

FIG. 2 is a front, partially cross-sectional, view of a plasma tube according to the invention associated with a reflex-klystron tube.

FIG. 1 shows a vacuum sealed glass tube **1**, filled with a noble gas under low pressure, for example xenon. The pressure is between 0.02 and 0.2 millimeter of mercury. Inside the tube are placed an oxide-coated cathode structure **2** and its heater **3**, a grid **4** and an anode structure **5**.

A fine mesh grid **4**, the dimensions of the meshes being approximately between one-tenth to one millimeter, is supported by a metallic cylinder **41** surrounding the cathode structure **2** and secured thereto by plate-like ring **42**. An anode structure **5**, brought to a variable modulating voltage by means, not shown, consists of a reentrant cavity resonator **50** having a lateral wall **54** and a ridged end wall **51**. This cavity resonator is so dimensioned as not to vibrate in the usual reentrant cavity mode, but in the TEM mode as regards the coaxial portion, the remainder of the cavity resonator forming a wave guide section beyond cut-off, i.e. whose diameter is less than the diameter of a waveguide the cut-off frequency of which is at least equal to the higher limit of the frequency range of the microwave oscillator tube associated with the plasma tube. The coaxial portion of the cavity resonator has an axial length near one quarter of the wavelength corresponding to the lower frequency of the frequency range of the associated oscillator tube. Thus the coaxial cavity resonates when the xenon gas is not ionized as a coaxial cavity resonator closed at one end and open at the other end on a resonant wavelength substantially equal to four times its height. In a typical example, the higher limit frequency being 9000 mHz. corresponding to a wavelength of 3.33 cms., the axial length of the cavity resonator **50** is 7 mms. and the diameter of the waveguide **54** is 14 mms., the corresponding cut-off frequency being $3.10^{10}/1.707\times1.4=12{,}600$ mHz. and consequently the waveguide is beyond cut-off for a signal at 9000 mHz.

A pair of wave permeable gas tight window members **52** and **53** as of alumina ceramic are sealed across the outer wall of cavity resonator **50**, near the closed end thereof.

Grid **4** is placed at a sufficient distance from the inner conductor **51** of the coaxial cavity in order to prevent the microwave energy from the evanescent mode in waveguide **54** from escaping into the cathode side of the discharge tube. The microwave fields are therefore quite weak in the neighborhood of the grid, and thus the influence of the cathode-grid region and of the grid-anode region adjacent to the grid on the plasma tube operation is significantly reduced.

The ionization process is initiated by applying a direct voltage between anode **5** and heated cathode **2** by means of variable voltage supply **8**. The plasma, formed by the collisions of the electrons at their exit from the grid **4** with the atoms of the noble gas, diffuse into the inside of the anodic part of the tube. The electron density is maximal in the neighborhood of the end of the central conductor **51**. This condition of operation is favorable for obtaining a large variation of the resonant frequency of the cavity since this cavity, operating in the TEM mode, has a maximal electric field in the open terminal plane passing through the end of the central conductor **51**.

The characteristics and performance of such a plasma tube for a xenon pressure of 0.02 mm. of mercury, are the following:

Maximal ionization potential between anode and cathode ____volts__	60
Average operating voltage between anode and cathode ____do____	20
Maximal current ____ma__	200
Approximate maximal density of the plasma per cm.^{3} ____	10^{12}
Resonant frequency for zero direct current in a typical plasma tube ____mHz__	8000
Resonant frequency for a current of 100 ma. mHz__	11000
Approximate loaded Q ____	200

FIG. 2 represents a plasma tube designated generally by the reference numeral **100**, and associated with a reflex-klystron **200**, the two tubes **100** and **200** constituting an over-all unit often called "klysmatron," the name coined from the words "klystron" and "plasma."

The plasma tube **100** is different from the one in FIG. 1 only as regards its outer envelope. Its different parts already represented in FIG. 1 are denominated by the same reference numerals increased by 100.

A hollow metallic relatively thick walled chamber **150** is defined by and bounded by cylindrical side wall **154** and end wall **105** provided with a central, hemispherically ended, post **151**. The side wall **154** is vacuum sealed to a socket **110** which coaxially supports cathode assembly **102** and cylinder **141**, this last cylinder carrying grid **104**. The chamber **150** is filled in use with xenon to a low pressure within the range above indicated.

A pair of port terminals **6** and **7** form input and output waveguide terminal sections, respectively, of the cavity resonator **150** for applying wave energy to the cavity and for abstracting wave energy therefrom. A pair of R.F. window members **152** and **153** are vacuum sealed across the input and output terminals. An input flange **156** as of copper connects to the output flange **256** of a reflex-klystron oscillator **200**. An output flange **158** connects to a load (not shown). A pair of capacitive phase adjusting posts **155** and **157** are provided, respectively extending into the input and output waveguide sections **6** and **7** from the broad wall thereof. The post **155** adjusts the effective electric length of the guide between the cavity resonator of the reflux-klystron and the cavity resonator **150** for impedance matching.

Part of the reflex-klystron **200** which is of a conventional type has been cut away to show cathode assembly **202**, reentrant cavity resonator **250**, reflector electrode **260**, stepped output waveguide **257** and window member **252**. The flanges **156** and **256** can be secured together as by screws or brazing; if assembling is achieved by vacuum sealing, then the vacuum envelope of the klystron-plasma tube assembly is completed through the intermediaries of output waveguide **257** and input waveguide **6**; window member **152** can be omitted.

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

What I claim is:

1. A variable reactance plasma tube adapted to oscillate in a given frequency range comprising a vacuum sealed envelope filled with a low pressure gas, a cathode assembly, a grid and an anode assembly, said anode assembly forming a metallic reentrant cavity resonator having a coaxial cavity portion and an adjacent cylindrical waveguide portion extending substantially up to to the grid, said cylindrical waveguide portion being beyond cut-off for all the frequencies comprised in said frequency range, means for coupling to said coaxial portion microwave energy having a frequency in said range, means for abstracting from said coaxial cavity portion microwave energy and means for applying a variable voltage between said cathode and anode assemblies.

2. A variable reactance plasma tube adapted to oscillate in a given frequency range comprising a vacuum sealed envelope filled with a low pressure gas, a cathode assembly, a grid and an anode assembly, said anode assembly forming a metallic reentrant cavity resonator having a coaxial cavity portion, the length of which is substantially equal to the quarter of the wavelength corresponding to the lower frequency of said frequency range, and an adjacent cylindrical waveguide portion extending substantially up to the grid, said cylindrical waveguide portion being beyond cut-off for all the frequencies comprised in said frequency range, means for coupling to said coaxial portion microwave energy having a frequency in said range, means for abstracting from said coaxial cavity portion microwave energy and means for applying a variable voltage between said cathode and anode assemblies.

3. A variable reactance plasma tube according to claim **1** in which the means for coupling and abstracting microwave energy to and from the coaxial cavity portion of the reentrant cavity resonator are two waveguide sections aligned with each other and radially directed with respect to said coaxial cavity portion and coupled thereto by means of radio frequency permeable window members.

4. A frequency modulated oscillator tube assembly comprising a klystron tube oscillating in a given frequency range, having an evacuated envelope and at least one cavity resonator, a variable reactance plasma tube comprising a vacuum sealed envelope filled with a low pressure gas, a cathode assembly, a grid and an anode assembly, said anode assembly forming a metallic reentrant cavity resonator comprising a coaxial cavity portion having an inner conductor and an outer hollow cylindrical conductor longer than the inner conductor, the portion of said outer conductor which is longer than said inner conductor forming a waveguide beyond cut-off for all the frequencies comprised in said frequency range and extending substantially up to the grid, means for vacuum tightly coupling said klystron cavity resonator to said coaxial cavity portion of said reentrant cavity resonator, means for abstracting from said coaxial cavity portion microwave energy and means for applying a variable voltage between said cathode and anode assemblies.

5. A frequency modulated oscillator tube assembly comprising a klystron tube oscillating in a given frequency range, having an evacuated envelope and at least one cavity resonator, a variable reactance plasma tube comprising a vacuum sealed envelope filled with a low pressure gas, a cathode assembly, a grid and an anode assembly, said anode assembly forming a metallic reentrant cavity resonator comprising a coaxial cavity portion having an inner conductor and an outer hollow cylindrical conductor longer than the inner conductor, the portion of said outer conductor which is longer than

said inner conductor forming a waveguide beyond cut-off for all the frequencies comprised in said frequency range and extending substantially up to the grid, a first waveguide section vacuum tightly coupling said klystron cavity resonator to said coaxial cavity portion of said reentrant cavity resonator, radially directed with respect to said coaxial cavity portion, a second waveguide section aligned with said first section for abstracting from said coaxial cavity portion microwave energy, radio frequency permeable window members disposed in said waveguide sections, and means for applying a variable voltage between said cathode and anode assemblies.

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