Oct. 10, 1967 J. FEINSTEIN 3,346,766

MICROWAVE COLD CATHODE MAGNETRON WITH INTERNAL MAGNET

Filed March 13, 1964

FIG. 1

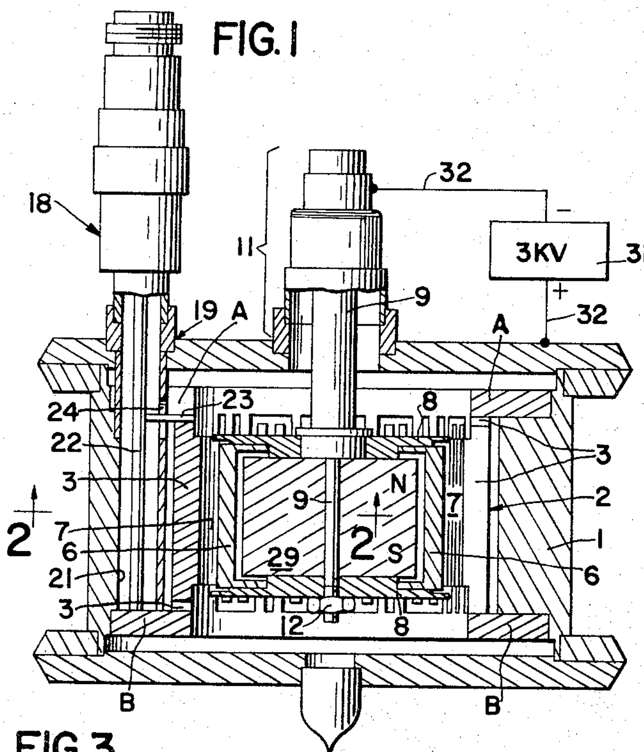


FIG. 2

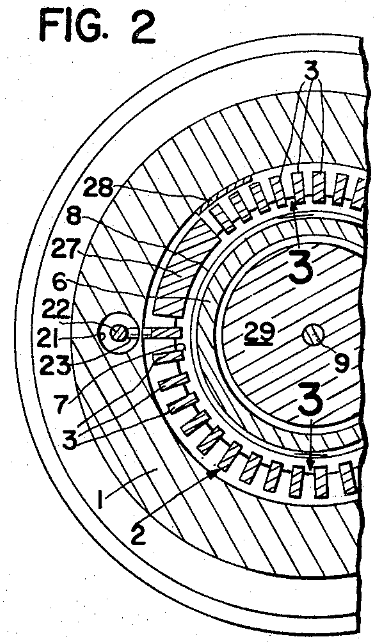


FIG. 3

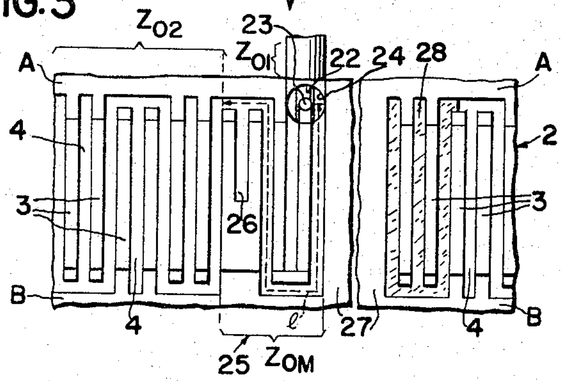


FIG. 4

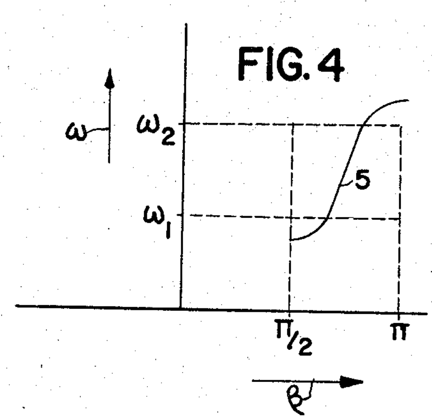
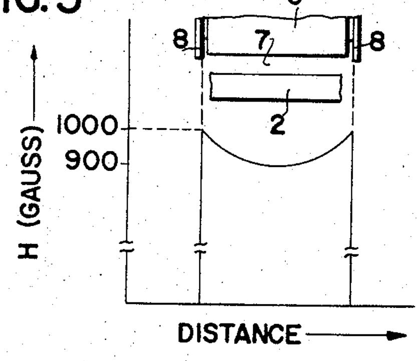


FIG. 5



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MICROWAVE COLD CATHODE MAGNETRON WITH INTERNAL MAGNET

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ABSTRACT OF THE DISCLOSURE

A cold cathode magnetron tube is disclosed wherein a permanent magnet is disposed inside the cold cathode structure. A pair of pole pieces are disposed at the ends of the permanent magnet and arranged such that they overhang the sides of the magnet to improve the uniformity of the axial magnetic field in the magnetron interaction region.

In a preferred embodiment, the pole pieces also overhang the cathode emitter to form the end hats for the cold cathode. In the preferred embodiment, the cold cathode is radially spaced apart from the permanent magnet to inhibit heat transfer from the cathode to the permanent magnet in use.

Heretofore cold cathode crossed field amplifier or oscillator tubes of circular geometry, hereinafter called magnetrons, have been built. As used herein, "cold cathode" means the cathode electrode is operated at a temperature in use below the typical thermionic emission temperature for the cathode electrode material such that if the cathode electrode is also the emitter the predominant emission mechanism is other than thermionic such as secondary emission, or high field emission, etc. These prior cold cathode magnetrons have included permanent magnets for generating the magnetic field in the beam field interaction region of space or gap. These permanent magnets have heretofore been disposed externally to the tube envelope spanning the interaction gap. Some of these magnets have been cylindrical, some have been C-shaped, and others have been bowl-shaped completely surrounding the interaction gap. Because of high flux leakage, all such magnets have been relatively heavy and bulky usually constituting the major size and weight factor for the entire tube assembly.

In the present invention, the permanent magnet for producing the magnetic field in the interaction space of a cold cathode magnetron is disposed within the cold cathode electrode whereby the size and weight of the permanent magnet is substantially reduced as by, for example, a factor of **10**. The magnet includes a pair of pole pieces at the ends which project outwardly over the outer surface of the magnet to improve the uniformity of the field. The overhanging pole pieces also provide end hats for the cathode.

The principal object of the present invention is to provide an improved magnetron tube with magnet having reduced size and weight.

One feature of the present invention is the provision of a permanent magnet disposed within a hollow of the cathode electrode of a cold cathode magnetron oscillator or amplifier and including pole pieces at the ends of the magnet which overhang the sides of the magnet for generating the static magnetic field in the beam field interaction space whereby the size and weight of the tube is greatly reduced.

Another feature of the present invention is the same as the preceding feature wherein the tube apparatus is a noise generator, the anode circuit of which serves to amplify and couple out noise signals, over a broadband of

frequencies, which are generated in the space charge spokes internally of the magnetron tube.

Other features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

FIG. 1 is a longitudinal sectional view of a magnetron incorporating the features of the present invention;

FIG. 2 is a transverse sectional view of the tube structure of FIG. 1 taken along lines **2—2** in the direction of the arrows;

FIG. 3 is an enlarged view of a portion of the structure of FIG. 2 taken along lines **3—3** in the direction of the arrows;

FIG. 4 is a ω—β diagram showing the dispersion characteristics for the slow wave circuit of the tube of FIGS. 1 and 2; and,

FIG. 5 is a plot of magnetic field intensity H versus distance along the axial centerline of the interaction gap and also showing the relative position and shapes of anode, cathode, magnet H-field lines for the tube of FIGS. 1 and 2.

Referring now to FIGS. 1 and 2, there is shown the novel amplifier tube apparatus of the present invention. More particularly, there is shown a hollow cylindrical main body member **1** as of copper having end closing walls as of copper and forming the vacuum wall of the tube.

An arcuate severed interdigital slow wave circuit **2** is coaxially disposed of the main body **1**. The slow wave circuit **2** comprises a pair of interdigitated conductive comb structures including a pair of axially spaced mutually opposed conductive backbone portions A and B forming a two wire line (see FIG. 3) and an array of interdigitated conductive plate-like teeth **3**. The teeth **3** are bifurcated at **4** to introduce an inductive reactive loading in series with the two conductors A and B, whereas the space between adjacent teeth **3** of opposed conductors develops a capacitive voltage in shunt with the conductors A and B. The anode electrode structure comprises the cylinder **1** and anode circuit **2**.

The slow wave circuit **2** has a fundamental forward wave space harmonic mode of operation as seen by curve **5** in the ω—β diagram of FIG. 4 and forms the subject matter of and is claimed in copending U.S. patent application 637,007, filed May 8, 1967, as a continuation application of U.S. 350,504, filed Mar. 9, 1964, both applications being assigned to the same assignee as the present invention. The parent application is now abandoned in favor of the continuation.

A hollow cylindrical cold cathode emitter electrode **6** as of beryllium—copper or aluminum is coaxially disposed of the slow wave circuit **2** to define an annular electronic interaction region **7** in the space between the cathode **6** and the slow wave circuit **2**.

A pair of cathode pole pieces **8** as of iron, close off the open ends of the cathode emitter **6** and also serve as cathode end hats. A cylindrical cathode support stem **9**, as of nonmagnetic stainless steel, extends axially of and through the tube envelope via high voltage insulator assembly **11** of the conventional design for supporting the cathode emitter coaxially thereof. The stem **9** is threaded at its end and the cold cathode with its end hats **8** are captured on the stem by nut **12**.

A low pressure gas fill as of H_2, A, or Xe gas at 10^{-1} mm. Hg pressure is employed in the interaction space to start the cold cathode discharge when the tube is operated as a noise generator. Cold cathode gas filled magnetron oscillators are described in Crossed-Field Microwave Devices, vol. 2, Okress, page 301–313 (1961). This mode of operation will be more fully described below. When operated as an amplifier, the R.F. drive power is sufficient to start the electron build-up for the cold cathode under high vacuum conditions. The cathode electrode structure includes emitter **6** together with end hats **8**.

R.F. power output is extracted from the tube via coaxial line **18** for transmission to a suitable utilization device, not shown. The coaxial line **18** enters the tube body **1** at **19** and is formed in the side wall of the main body by means of an axially directed bore **21** which serves as the outer conductor for the coaxial line **18** within the tube body **1**. The center conductor **22** of the coaxial line **18** passes axially through the bore **21** and is electrically connected to the outer conductor at the bottom of the bore **21** thereby providing a short.

A conductive finger **23** extends radially inwardly of the tube body from the center conductor **22**. The finger **23** is located a quarter wavelength away from the shorted end of the coaxial line **18** forming a coaxial T section to reflect a high impedance to wave energy which is propagating toward the shorted end of the coaxial line at the finger **23**. An aperture **24** is provided in the side wall of the outer conductor of the coaxial line to accommodate passage of the finger **23** therethrough. The finger **23** connects to slow wave circuit **2** via the intermediary of a matching quarter wave section as shown in FIG. 3.

The coaxial line **18** has a certain characteristic impedance such as 50Ω. The interdigital line **2** has a certain characteristic impedance such as 85Ω. The matching section **25** is made a quarter electrical wavelength long, along path *l*, including the effect of the reactive loading of section **26**. The characteristic guide impedance Z_{om} of the quarter wave section **25** is dimensioned to equal the square root of the product of the slow circuit characteristic impedance Z_{02} and the coaxial line impedance Z_{01}, that is $Z_{om}=\sqrt{Z_{01}\times Z_{02}}$. With this condition for section **25** and the provision of the quarter wave choke support at the T section of coaxial line **18**, there is obtained a substantially reflectionless flow of power from the slow wave circuit **2** to the coaxial line **18**.

A circuit sever **27** is provided at the terminal end of the slow wave circuit and matching section **25**. The sever **27** subtends approximately 45° of arc. The slow wave circuit **2** has its beginning at the other end of the sever **27**. A lossy member **28** as of carbon impregnated alumina is disposed adjacent the first half section (period) of the slow wave circuit inbetween the circuit **2** and the inside wall of the envelope **1** for absorbing wave energy traveling in the backward direction on the slow wave circuit **2** to prevent reflection thereof which might otherwise produce unwanted oscillations of the tube.

A hollow cylindrical permanent magnet **29** is coaxially mounted within the cathode emitter electrode **6** inbetween the cathode stem **9** and the emitter **6**. The permanent magnet **29**, as of Alnico VIII is axially magnetized to provide a north pole N at one end and a south pole S at the other end of the magnet cylinder. The magnet **29** is preferably radially spaced away from the inside wall of the emitter **6** to reduce thermal conduction from the cathode to the magnet **29**. However, at its inside diameter the magnet **29** preferably makes good thermal contact with the cathode stem **9** to enhance conduction of heat from the magnet to a heat sink external of the tube envelope **1** via the stem **9**.

The cylindrical internal magnet **29** with magnet pole pieces **8** produces an axial magnetic field intensity H in the electronic interaction gap **7** as shown in FIG. 5. The field intensity is (for example) 900 gauss in the transverse center plane of the gap and increases to approximately 1000 gauss at the ends of the gap **7** adjacent the end hats **8**. The dip in the center of the field helps to confine the space charge to the center interaction region of the slow wave circuit **2** where the electronic interaction voltages of the slow wave circuit **2** are most intense.

The end hat pole pieces **8** substantially overhang radially outwardly over the outer perimeter of the magnet **29** and cathode **6** to guide the magnetic flux lines H for minimizing stray field and for shaping the field in the interaction region **7**. The end hat pole pieces **8** substantially straighten the field lines as they pass through the interaction region **7** thereby preventing excessive beam interception on the circuit **2**.

In operation, a cold cathode electrode to anode electrode voltage, as of 3 kv., is applied via power supply **31** and leads **32**. The applied D.C. voltage is of sufficient amplitude to cause a breakdown in the gas fill to produce space charge which initiates operation of the tube. Steady state operation occurs due to the secondary emission from the cathode **6**. Space charge noise signals present in the interaction gap excite a wave on the slow wave circuit **2**. The noise wave energy on the circuit with frequencies in the band of ω_1 to ω_2, as shown in FIG. 4, are amplified by cumulative electronic interaction with the space charge to produce rotating spokes of space charge rotating with a synchronous velocity corresponding to electron energy of 500 v. The amplified noise energy over a broad band of frequencies such as an octave of bandwidth is extracted from the circuit **2** via output matching section **25** and coaxial line **18** and transmitted to a suitable utilization device, not shown. The electronic interaction produces electron back/bombardment of the cold cathode **6** to produce secondary emission therefrom to replenish the space charge collected on the anode structure. The space charge is trapped in equipotentials in the presence of the axial magnetic field and continues to recirculate around the cathode **6** until collected. The sever **27** subtends sufficient arc to produce debunching of the space charge passing through the drift space adjacent the sever **27** thereby preventing electronic feed-back oscillations.

A typical noise generator tube of the above-described type produces noise over an octave of bandwidth centered at 1.5 gc. The tube may also be operated as a conventional two port forward or backward wave amplifier. In this case, the tube would be essentially the same tube as above-described except that the gas fill need not be used, it being replaced by a high vacuum and except for the provision of an input coaxial line, not shown, identical to line **18**. The input line, in this case, is connected to the beginning of the slow wave circuit **2**, via a quarter wave stub section, as above-described, and quarter wave impedance matching section **25**, as above-described.

The R.F. signal to be amplified produces sufficient cathode back/bombardment and secondary emission to sustain amplification and power output. In such a tube at L band, 20 db gain is obtained over an octave of bandwidth at a power output of 1 kw. A conventional external magnet for such a tube would weigh approximately 10 pounds, whereas, for the above-described L band tube, the magnet weight is 1 pound, thereby effecting an order of magnitude reduction in magnet size and weight.

The present invention has been described with regard to a particular magnetron type wherein the cold cathode electrode was also the cathode emitter. This is not a requirement of the present invention. The cold cathode electrode, i.e., the electrode structure operating at cathode potential, could be non-emissive and electron emission supplied entirely from a separate thermionic emitter and injected into the annular electron stream in the conventional manner. Also, the tube may be operated as an oscillator by judicious choice of wave circuit such as conventional strapped vanes and deletion of the sever **27**.

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 is claimed is:

1. In a magnetron microwave tube apparatus; means forming a generally cylindrical cathode electrode structure; means for producing an arcuate stream of electrons adjacent said cold cathode electrode; means forming an anode electrode structure coaxially disposed of said cathode electrode in spaced apart relationship and defining an electronic interaction region therebetween, said anode electrode including an arcuate wave circuit facing said cylindrical cathode electrode structure for electronic interaction between waves on said circuit and the stream of electrons; means forming a permanent magnet disposed within said cathode electrode for generating an axially directed magnetic field in said interaction region to cause the electron stream to move tangentially to said wave circuit to effect cumulative electronic interaction between the electron stream and waves on said anode circuit; means for extracting microwave energy from said circuit, means forming an evacuable envelope enclosing said magnet, said cathode and the magnetron interaction region, the improvement comprising, means forming a pair of magnetic pole pieces disposed within said evacuable envelope at the ends of said permanent magnet, said pole pieces projecting toward said anode electrode structure and overhanging the sides of said permanent magnet to improve the uniformity of the magnetic field in the magnetron interaction region.

2. The apparatus according to claim 1 wherein said cathode electrode includes an arcuate cold cathode emitter member made of a material having a secondary emission ratio substantially greater than 1, said emitter also serving as said means for producing the electrons of said arcuate stream.

3. The apparatus according to claim 2 wherein said evacuable envelope is partially evacuated and wherein said permanent magnet means is disposed inside said envelope and is radially spaced from said cold cathode emitter member to create at least a partially evacuated void therebetween to reduce conduction of heat from said emitter to said magnet in use.

4. The apparatus according to claim 1 wherein said pole pieces also overhang the emitting surface of said cylindrical cathode electrode to serve as end hats for said cathode electrode.

5. The apparatus according to claim 1 wherein the tube apparatus is a noise generator, and said wave circuit is a slow wave circuit, said circuit being dimensioned to amplify space charge noise signals internally generated within the tube apparatus.

6. The apparatus according to claim 5 wherein said slow wave circuit includes a pair of interdigitated conductive comb structures with interdigitated teeth portions, and wherein said teeth portions are bifurcated to provide an interdigital slow wave circuit having a fundamental forward wave space harmonic for cumulative electronic interaction with said electron stream over a broad band of frequencies.

7. The apparatus according to claim 5 wherein the tube includes a crossed-field interaction region filled with a gas which ionizes during operation of the tube to produce free electrons and ions to enhance starting of the electronic discharge within the tube.

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