May 19, 1964 D. A. WILBUR 3,134,047

NEUTRODE CROSSED FIELD VOLTAGE TUNED OSCILLATOR

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Fig. 2.

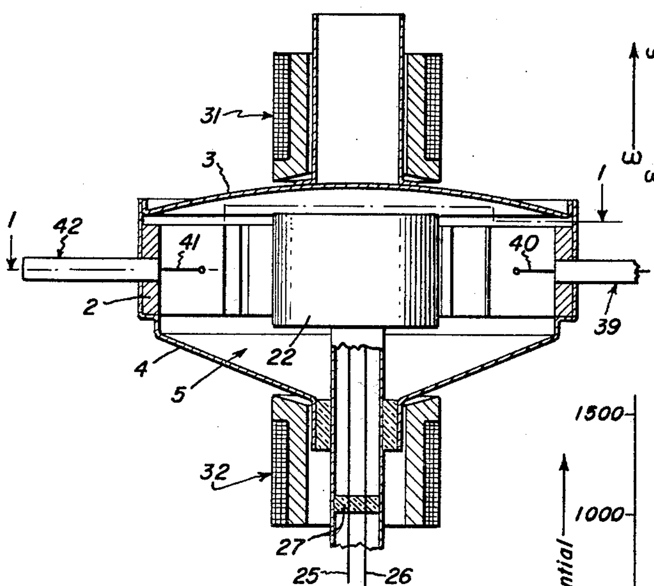
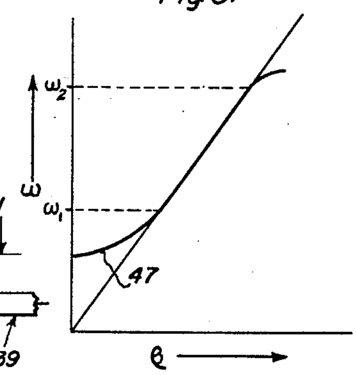


Fig. 3.



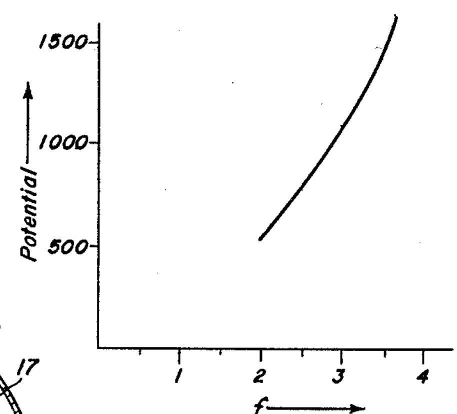
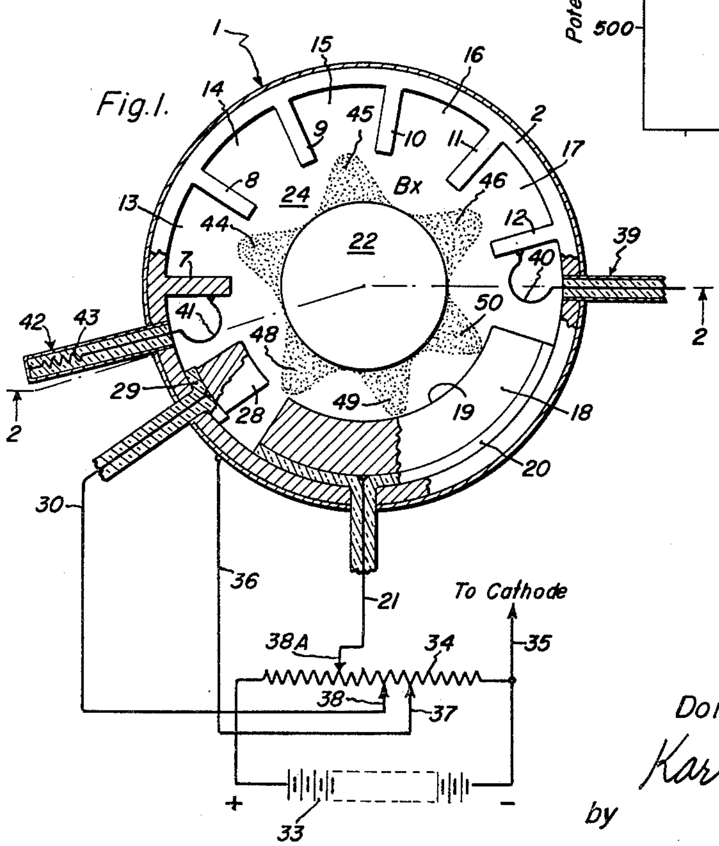


Fig. 4.

Fig. 1.



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NEUTRODE CROSSED FIELD VOLTAGE TUNED OSCILLATOR

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My present invention relates to an electron tube apparatus of the magnetron type and to a novel method of operating such a tube to achieve frequency tuning thereof.

In the operation of magnetron devices, it is frequently advantageous to have the magnetron adaptable to operate over a band of frequencies rather than merely at a single frequency alone. Various techniques for tuning the magnetron or the circuitry associated therewith have been devised and utilized with considerable success and techniques for voltage tuning of magnetrons in the manner such as disclosed in Patent No. 2,774,039 granted to Philip H. Peters, Jr. and Donald A. Wilbur, on Dec. 11, 1956 and entitled Method of Varying the Output Frequency of Magnetron Oscillators, has also been utilized with remarkable success. In general, in accordance with the method of this patent, the output frequency of a magnetron is controlled by controlling the anode to cathode potential difference under conditions of limited cathode emission and/or heavy anode loading. While this method is very effective to achieve frequency tuning of a magnetron, and even further advantage would exist in tuning a magnetron without varying the anode potential and thus, maintaining the direct anode current at a steady minimum value during operation.

It is, therefore, an object of my invention to facilitate tuning of a magnetron over a frequency band while maintaining the direct anode current at a relatively constant value.

The frequency of operation of a non-resonant magnetron apparatus having a reentrant space charge and an active anode section for which the frequency versus phase-shift-per-unit-length along the anode characteristic has a portion lying in a line through the origin of a graph plotting this characteristic, depends upon the spacing between the electron bunches formed in the interaction region since the passage of these bunches produce the potential changes at the anode segment tips. For example, the faster the bunches pass the anode segments or the smaller the interbunch spacing and the larger the number of bunches passing the segments the larger will be the number of brunches that pass per unit time and the greater the number of potential changes at the anode segments. Accordingly, the higher will be the frequency generated by the passing bunches.

In accordance with my present invention, frequency control is achieved in a magnetron by the provision of a non-resonant, slow wave structure of any conventional type along a portion of its anode circumference and a neutrode electrode having a regular, resistive surface, uniformly spaced from a centrally disposed cathode along another portion of the anode. The frequency control is achieved by establishing a certain value of direct electric field in an interaction region between the slow wave structure and a spaced, centrally disposed cathode and by variably controlling the value of electric field between the neutrode and the cathode. The electron beam in the

interlectrode region is made reentrant and along the portion thereof between the cathode and neutrode, there is no interchange of energy between the beam and the electromagnetic field. However, the velocity of the bunches of the beam are controlled by the value of the ratio of electric field to magnetic field in this region. Thus, the rate at which the beam bunches traverse this region may be controlled by neutrode potential and consequently, the reentry rate of the bunches into the interaction region between the cathode and slow wave structure may be controlled. Since the frequency of operation of the magnetron is affected by the spacing between adjacent bunches traversing the interaction region and since the spacing between bunches is affected by the rapidity of reentry thereof into the interaction region, the frequency of operation of the device is controllable by the neutrode potential.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself together with further objects and advantages thereof, may best be understood with reference to the drawing in which:

FIGURE 1 illustrates a simplified, cross-sectional plan view of a magnetron embodying my invention and operable in accordance with my invention,

FIGURE 2 illustrates a cross-sectional elevation of the magnetron shown in FIGURE 1,

FIGURE 3 shows a graph representing a plot of the angular velocity versus phase-shift-per-unit-length of the high frequency wave propagated along the anode and useful for explaining the operation of my invention, and

FIGURE 4 shows a graph representing a plot of the neutrode potential versus operating frequency of a magnetron according to my invention.

Referring now more particularly to FIGURES 1 and 2 of the drawings for a more detailed description of the invention, **1** represents generally an entire magnetron apparatus embodying my present invention. The apparatus is shown in simplified form and without the details of certain parts not forming any essential part of the invention so as to simplify and clarify the description with respect to the parts thereof more directly associated with the invention.

The magnetron includes an anode member **2** disposed between a pair of dome shaped members **3** and **4** for establishing an evacuated enclosure **5** containing the electrodes of the magnetron. The anode **2** includes a plurality of vanes **7**, **8**, **9**, **10**, **11** and **12** along a portion of the circumference thereof projecting radially inwardly to form a plurality of cavities **13**, **14**, **15**, **16** and **17** between pairs of vanes to form a non-resonant slow wave structure for supporting propagation of an electromagnetic wave. The vanes are preferably of uniform length and terminate along a right circular cylindrical surface having an axis along the axis of the magnetron. The particular slow wave structure shown is only one form that may be utilized and it is within the purview of my inveniton to provide other types of non-resonant, slow wave structures with cavities in the form of slots, holes and slots or other types.

In accordance with a feature of my invention, along another portion of the anode circumference is mounted a neutrode electrode **18** having an inner arcuate surface **19** preferably lying in the mentioned cylindrical surface.

The neutrode electrode is insulated from anode member 2 by an insulator 20 disposed between the anode 2 and neutrode electrode 18 to enable application of direct potentials to the neutrode, different from potentials applied to the anode member 2. For application of such potentials, a conductive line 21, having an insulating coating extends through an aperture in anode member 2 and is in conductive contact with neutrode electrode 18. Although the neutrode may be conductive, it preferably presents a resistive surface, particularly in cases of relatively long neutrodes. This is sufficiently large to tend to maintain the bunched character of the electron bunches. To this end, the neutrode 18 may be totally resistive material. Suitable materials for the resistive material in either of these alternative embodiments are alumina impregnated with carbon, hydrogen fired aluminum titanate, barium titanate or Kanthol. Still other forms which the neutrode 18 can take are a conductive member with spaced slots filled with resistive material and resistive material covered by a slotted conductive member.

In general, neutrode 18 is resistive enough to assure maintenance of the beam bunches and typically its resistance is much smaller than the resistance presented by the slow wave structure. A second anode portion, suitably insulated from that shown would be operable as a neutrode for the present purposes, but the electromagnetic wave generated thereon would have to be appropriately removed from the magnetron and utilized or dissipated. This would involve additional structure and in cases of dissipated energy, a significant loss. The neutrode 18 may serve the purpose of such a vaned anode structure without the disadvantages of relatively high resistance, complexity and energy loss since it does not generate an electromagnetic wave. The direct current conduction is minimized in the resistive material of neutrode 18.

The neutrode 18 in presenting a resistance the same as a slow wave structure tends to have the same bunching effect on electrons in a beam passing it, as does the actual slow wave structure. The resistive character of it enables the generation of a potential gradient along its length in response to passing bunches and in turn enhances the bunching.

Along the interior of anode member 2 is mounted a cathode 22 having a circular, cylindrical surface 23 generally concentric with anode 2 and coated with a suitable electron emission enhancing material. The cathode is uniformly spaced from the vane tips to form an interaction region 24 therebetween. Heater means, not shown, are provided for raising the temperature of the emissive surface to copious electron emission. Electrical energy is provided to the cathode heater through a pair of leads 25 and 26 extending through an insulator 27 disposed in an aperture of dome shaped member 4.

In the anode block between neutrode 18 and the slow wave structure of the anode is disposed a short anode member 28 mounted in insulated relationship with respect to the anode member 2 by an insulator 29 between these members. The anode member 28 may have a potential applied thereto through a conductive line 30 having an insulating coating and extending through an aperture in the anode member 2.

The interaction region 24 of the magnetron is immersed in an axial, direct magnetic field represented by the cross (x) at B in FIGURE 1 and produced by a pair of electromagnets 31 and 32 at opposite ends of the magnetron. Suitable potentials are applied to the respective electrodes of the magnetron by a suitable power supply represented by a battery 33 and potentiometer resistor 34 connected across the battery. The cathode 22 is directly connected to negative terminal marked (−) through a lead 35, the anode 2 is connected through a lead 36 to a potentiometer arm 37 contacting an intermediate point on resistor 34, anode 28 is connected through lead 30 to another potentiometer arm 38 positioned at another intermediate point on resistor 34 and neutrode 18 is connected through lead 21 to a potentiometer arm 38A set at still another intermediate point of resistor 34.

Electromagnetic energy may be abstracted from the magnetron through a coaxial line 39 having its inner conductor terminating in a coupling loop 40 which is conductively attached to a side of vane 12. During operation of the magnetron, electromagnetic energy flows along the slow wave structure toward output line 39. For suppressing energy reflected from the region of the magnetron anode having the output connection, a coupling loop 41 connected to a side of vane 7 and to a center conductor of a coaxial line 42, is effective to couple and conduct such reflected energy to a resistor 43 connected across the conductors of line 42. The resistor 43 is preferably of a value equal to the characteristic impedance of the line so as to completely absorb such reflected energy and prevent its reflection back into the anode.

In the operation of the magnetron in accordance with my invention, the cathode 22 is heated to a temperature of copious electron emission, a positive potential is applied to the anode 2 with respect to cathode 22 so as to establish an electric field in the interaction region 24 and a magnetic field represented by the cross designated B is established axially along the magnetron so as to have lines of force perpendicular to the electric field lines. Positive potentials which may be different in value are applied to anode 2, neutrode electrode 18 and anode 28 with respect to the cathode 22. Under these conditions the cathode emits electrons which enter the interaction region and in a manner known, the electrons tend to form into bunches or spokes as shown at 44, 45 and 46 and travel as bunches along the interaction region in a clockwise direction as shown in FIGURE 1 of the drawings. As shown in this figure, the bunches traverse the adjacent pairs of vanes in a manner well known, induce high frequency potentials across these vane tips and establish an electromagnetic wave propagating along the vane portion of the anode as a slow wave structure. After each electron bunch of the beam passes vane 12 it enters the region between the cathode and the neutrode 18 and travels in a clockwise direction to the region of the magnetron where anode 28 is disposed.

The frequency versus phase-shift-per-unit of anode length, operating characteristic of a non-resonant anode structure is represented by the curve 47 shown in FIGURE 3 wherein the ordinate, ω, represents angular velocity and the abscissa, β, represents phase-shift-per-unit-length of an electromagnetic wave propagated along the non-resonant anode structure. In this figure it is observed that a certain portion of the curve having ordinate values between ω_1 and ω_2 lies along a straight line passing through the origin. The slope of this portion of this curve is equal to the value

$$\frac{\omega}{\beta}$$

at any point therealong which, in turn, is equal to the phase velocity, v_p, of an electromagnetic wave propagated along the anode. For proper energy interchange, the electron beam velocity is substantially equal to the phase velocity of the wave. Since the average electron velocity in crossed fields is proportional to the electric field involved, the return travel of each electron bunch past the neutrode 18 is dependent upon the potential applied to this neutrode. Therefore, the time of reentry of each bunch to the interaction region 24 is dependent upon this potential. Also, since the frequency of operation of the magnetron is affected by the rate at which the several bunches pass the gaps between adjacent vanes along the interaction region, the reentry rate of the bunches also affects the magnetron frequency. Thus, the potential applied to the neutrode 18 is effective in controlling the frequency of the magnetron without any potential change on the magnetron anode. The potential of anode 28 may be controlled to establish a gradually changing electric field rather than a discontinuous or rapidly changing one between the region of neutrode **18** and the interaction region to prevent debunching of the beam.

In the magnetron, electron bunches in the interaction region such as bunches **44**, **45** and **46** are effective in generating the electromagnetic wave along the slow wave portion of the anode. Simultaneously, in accordance with my invention, one or more electron bunches, such as those shown at **48**, **49** and **50** are in reserve in the region between cathode **22** and neutrode **18** and, as explained, their reentry into the interaction region depends upon the electric field in the region between cathode **22** and neutrode **18**.

The interrelationship between the frequency of operation of the magnetron and the number of bunches in the entire structure, the respective lengths of interaction region and neutrode and the velocity of bunches in these respective regions is expressed by the equation:

$$f=\frac{N}{\frac{l_1}{v_1}+\frac{l_2}{v_2}}$$

wherein N is the total number of electron bunches in the entire structure, l_1 is the length of the anode interaction region, l_2 is the circumferential length of the neutrode, v_1 is the velocity of the bunches in the region along l_1 and v_2 is the velocity of the bunches in the region along l_2. Since the velocity of the bunches in the respective regions between anode and cathode and between neutrode and cathode is proportional to the potentials applied to these electrodes, the frequency of operation of the magnetron is proportional to the expresssion:

$$\frac{N}{\frac{l_1}{v_1}+\frac{l_2}{v_2}}=\frac{N(v_1v_2)}{v_2l_1+v_1l_2}$$

wherein V_1 and V_2 represent, respectively, the potentials applied to the anode **2** and neutrode **18**, with respect to the cathode.

From this expression it is clear that the frequency of operation of the magnetron is proportional to the respective potentials applied to the anode and neutrode and if the anode potential is maintained substantially constant, the frequency of operation varies with the potential applied to the neutrode. This mode of operation is advantageous because the electron current to the neutrode is a minimum.

In accordance with a particular embodiment of my invention, a magnetron may be constructed with 6 vanes subtending substantially one-half of the entire anode circumference, with respective cathode and anode vane tips in radii of .108 inch and .170 inch to produce output at frequencies from 2000 kilomegacycles per second to 3600 kilomegacycles per second with an anode potential of 1100 volts, a magnetic field of 2500 gauss and neutrode potentials varied from 550 volts to 1650 volts. In this embodiment of invention, 6 electron bunches or spokes may be utilized in the region about the cathode for all different frequencies.

The tuning curve of a magnetron constructed according to these specifications is shown in the graph of FIGURE 4 of the drawings wherein the ordinate represents the potential difference between the neutrode electrode and cathode in volts and the abscissa represents the frequency of operation of the magnetron.

While the present invention has been described by reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A magnetron apparatus comprising an anode having a plurality of cavities separated by conductive segments therebetween along a predetermined portion thereof providing a slow wave structure, impedance means terminating said slow wave structure, an electrode along another portion of said anode, a cathode, said segments and said electrode each having extremities spaced from said cathode and defining therewith a reentrant electron path, said electrode being insulated from said anode and said cathode, means impressing an electrical potential on said electrode different from that applied to said anode to establish an electric field between said cathode and said electrode different from the electric field in the region between said anode and cathode, means producing a magnetic field between said cathode and both said anode and said electrode having lines of force substantially perpendicular to the lines of said electric fields to produce a different average velocity of electrons in the portion of said anode in the region of said electrode and determine the spacing between electron bunches in the portion of the electron path between said cathode and slow wave structure by the potentials applied to said electrodes.

2. A magnetron apparatus comprising a circular anode providing a terminated slow wave structure along a predetermined portion of the circumference thereof, a cathode disposed within said anode and being spaced from said slow wave structure and cooperating therewith to define an electron path, a neutrode electrode along another circumferential portion of said anode electrode insulated from said anode and being spaced from said cathode electrode whereby an electric field may be established between said cathode and said neutrode different from the field between said cathode and said anode by the application of a different potential thereto to produce a different average velocity of electrons in the space between said cathode as compared with the average velocity of electrons in the space between neutrode and said cathode and said terminated slow wave structure under the influence of a magnetic field having lines of force perpendicular to said mentioned electric fields so that the spacing of the electron bunches in the region between said terminated slow wave structure and said cathode is determined by the magnitude of the potential applied between said neutrode electrode and said cathode.

3. A magnetron apparatus comprising a circular anode member having a non-resonant slow wave structure along a portion thereof and a neutrode electrode having a resistive surface along another portion thereof and being insulated from said anode, cathode means equidistantly spaced from said anode member and said neutrode for providing an electron beam whereby said neutrode may be operated at different potentials with respect to said cathode than said anode for enabling control of the electric field in the region between said neutrode and cathode for controlling speed of electron bunches in said region.

4. A magnetron apparatus comprising a circular anode structure having a plurality of cavities formed along a predetermined portion of the circumference thereof by a plurality of radially projecting vanes and providing a slow wave structure including impedance means terminating said slow wave structure, a cathode electrode centrally disposed within said anode and spaced equidistantly from the inner ends of each of said vanes, a neutrode electrode insulated from said anode and extending along another circumferential portion of said anode, means impressing a direct current potential on said neutrode, means impressing a direct current potential on said anode independent in magnitude of the potential impressed on said neutrode, means producing a direct magnetic field in the region between said cathode and both said anode and said neutrode and at right angles to the electric field produced by the potentials impressed on said anode and said neutrode and cooperating therewith to establish a different average velocity of electrons about

said anode in the space between said cathode and said neutrode as compared with the average velocity of electrons in the space between said cathode and said slow wave structure.

5. A magnetron apparatus comprising a cathode, a plurality of electrodes surrounding said cathode in spaced relation with respect thereto and cooperating therewith to provide a reentrant electron beam path, said electrodes including a slow wave structure and impedance means terminating said slow wave structure, and two other electrodes spaced along the beam path and mutually insulated from each other and from said terminated slow wave structure, means impressing a voltage of pre-

determined magnitude on said terminated slow wave structure, means impressing voltages on said two other electrodes independent in magnitude of said anode voltage and from the voltage applied to the other of said electrodes, and means producing magnetic field in the region of said beam path perpendicular to the fields produced by said potentials.

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