Aug. 10, 1948. E. D. McARTHUR 2,446,826

MAGNETRON

Filed Aug. 14, 1943

Fig.1.

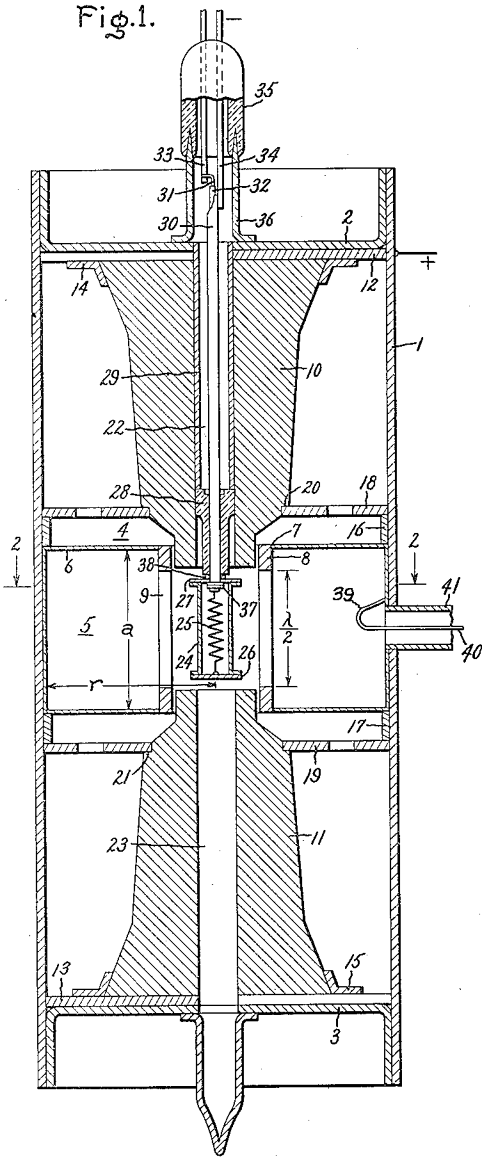


Fig.2.

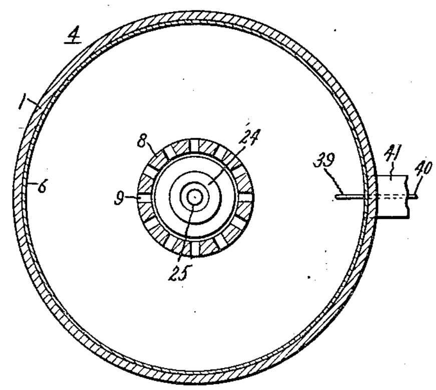


Fig.4.

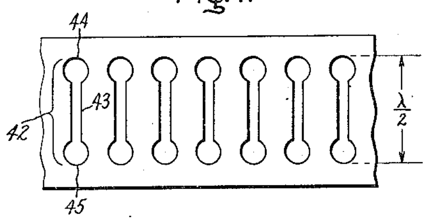


Fig.5.

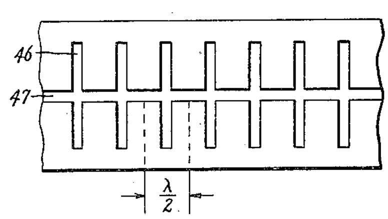


Fig.6.

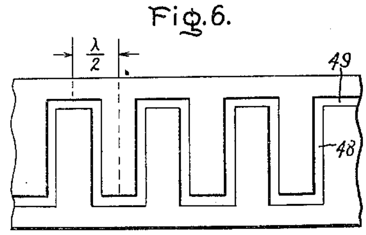
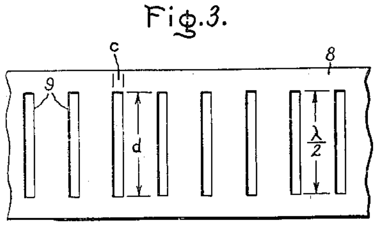


Fig.3.



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UNITED STATES PATENT OFFICE

2,446,826

MAGNETRON

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Application April 14, 1943, Serial No. 482,995

11 Claims. (Cl. 250—27.5)

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My invention relates to electric discharge devices and more particularly to electric discharge devices, such as magnetrons, for producing ultra high frequency electrical oscillations.

In the prior art arrangements wherein ultra high frequency oscillations have been produced in electric discharge devices by the utilization of the combined effects of magnetic and electric fields, the associated structure which has been energized by the oscillations or gyrations of the electrons constituting the electric discharge has been generally characterized by a certain degree of dissatisfaction due to the manner in which the energy has been extracted from the space charge. One of the principal disadvantages of the prior art arrangements has been the then apparent necessity for involving substantial field discontinuity at the anode surface or face, thereby causing an increase in losses and a consequent reduction in power output and efficiency.

In accordance with the teachings of my invention described hereinafter, I provide a new and improved ultra high frequency discharge device of the magnetron type wherein the field discontinuity at the surface of the anode is substantially lessened and whereby energy may be extracted from the electron beam or the space charge more effectively than that afforded by the prior art arrangements.

It is an object of my invention to provide a new and improved electric discharge device.

It is another object of my invention to provide a new and improved electric discharge device of the magnetron type.

It is still another object of my invention to provide a new and improved method for effecting energization of a space resonant region from an electric discharge produced by the interaction of electric and magnetic fields.

It is a still further object of my invention to provide a new and improved space resonant system constituting a space resonant region selectively responsive to a predetermined frequency and wherein energy is extracted from an oscillating space discharge by means of a plurality of tuned apertures.

It is still another object of my invention to provide a new and improved method for extracting energy from an oscillating electron beam produced by the interaction of a magnetic and electric field whereby a space resonant region may be energized by utilizing the radial and tangential components of the electric field associated with the electron beam.

Briefly stated, in the illustrated embodiments

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of my invention I provide a new and improved electric discharge device of the magnetron type wherein the oscillating electrons of the electric discharge produced by the interaction of a magnetic and an electric field effect energization of a tuned space resonant region defined by a shell-like or hollow annular member which also serves as an anode structure. The member which defines the annular hollow chamber or region may be considered as a dielectric wave guide of the hollow pipe type which is selectively responsive to a predetermined frequency of the oscillations produced by the electric discharge and is provided with a plurality of circumferentially spaced openings, such as tuned or resonant slots also resonant to a particular frequency. The frequency selectivity of the slots or apertures is determined by the longitudinal and circumferential dimensions thereof.

In accordance with further modifications of my invention, I provide in the face of the member defining the space resonant region or zone fret-like arrays of openings constituting circumferential and longitudinal slots or apertures tuned or correlated to the frequency of oscillation of the electric discharge and which utilizes both the radial and the tangential component of the electric field incident to the electrons constituting the space charge. In this manner, the space resonant region or chamber is selectively energized at a predetermined frequency.

For a better understanding of my invention, reference may be had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims. Fig. 1 diagrammatically illustrates an embodiment of my invention as applied to an electric discharge device of the magnetron type employing a pair of permanently magnetized pole pieces; Fig. 2 is a cross-sectional view of the annular member which defines the space resonant region or chamber; Fig. 3 is a plan view of the inner face of the resonant chamber or anode part which in conjunction with the cathode establishes the electric discharge path; Fig. 4 is a plan view of an alternative resonant slot array which may be employed in the anode part, and Figs. 5 and 6 are still further modifications of the aperture array which may be employed in the anode part and in which the apertures or slots are positioned to effect a fret-like configuration wherein both the radial and tangential components of the electric field incident to the oscillating electrons may be utilized effectively.

Referring now to Fig. 1 of the drawing, I have there illustrated my invention as applied to an electric discharge device, such as an ultra high frequency magnetron, including an elongated cylindrical container the lateral wall of which is provided by a single metallic tube 1 which consists of a ferromagnetic material such as cold-rolled steel or the like. The ends of the container or tube 1 are closed by flanged members 2 and 3 which are welded or otherwise hermetically joined to the inner surface of tube 1. The outer surface of the envelope may be provided with a plurality of radially extending fins not shown for the purpose of dissipating heat.

Within the container, and approximately at its central region, there may be provided an anode structure 4 shown in detailed plan view in Fig. 2. The anode structure comprises an annular shell-like or hollow member or a plurality of joined members preferably constructed of metal in order to define a space resonant chamber or wave guide 5 of annular configuration. For example, one way in which the region 5 may be formed or defined is by an annular metallic member 6 having a U-shaped configuration providing an elongated central opening 7 within which is placed an anode part which may be formed by a tubular metallic member 8 joined to or formed integral with member 6.

The longitudinal or axial dimension *a* of the chamber 5 is chosen with respect to the radial dimension *r* so that this region or chamber is resonant to a particular or predetermined frequency thereby rendering it selectively responsive to a predetermined frequency of the electrical oscillations produced by the electrons of the electric discharge produced by the interaction of the electric and magnetic fields described hereinafter.

The annular chamber 5 is designed to support a standing electromagnetic wave or a plurality of such waves, and although the chamber 5 may be "hollow," by the use of such term I nevertheless contemplate the provision of suitable dielectric means therein where the design of the electric discharge device and the chamber itself entails the presence of voltage of sufficient magnitude to make the use of insulating or dielectric means desirable or feasible.

Anode part 8 is provided with a plurality of resonant apertures in order to effect selective energization of the resonant chamber 5. For example, I may employ a plurality of circumferentially spaced longitudinal resonant slots 9 uniformly spaced around member 8. In order to obtain the most effective utilization of the electrical oscillations produced by the oscillating electrons, the number of slots should be even and should be correlated to the frequency of the electron oscillations or a multiple thereof. Member 6 and the anode part 8 may preferably consist of copper, and the member 6 may be supported at the inner surface of tube 1 by being brazed to that surface. In order to provide a magnetic field of sufficient intensity to permit the apparatus to function in its intended fashion, there are provided within tube 1 tapered magnetic pole pieces 10 and 11, which may be permanently magnetized, and which are directed axially of the tube 1 and which may extend a substantial distance within the opening provided by anode part 8 and in proximity to the ends of the resonant slots or apertures 9. To insure the existence of a magnetic field of desired intensity when the pole pieces 10 and 11 are permanently magnetized, these members should be constructed of a magnetizable material having a high coercive force and a high energy factor. One of the metals which may be used in this connection is that alloy or group of alloys of aluminum, nickel and cobalt. To provide a low reluctance connection between the base extremities of the pole pieces 10 and 11 and the lateral wall or tube 1, the pole pieces may be seated upon relatively thick disk-like members 12 and 13 consisting of a ferromagnetic material such as steel. For the purpose of securing the pole pieces firmly to these bases, use may be made of clamping rings 14 and 15 which are slipped over the pole pieces and welded to the base members. Accurate spacing of the pole pieces 10 and 11 with reference to anode structure 4 may be obtained by use of spacing rings 16 and 17 used in the manner indicated. As shown in Fig. 1, each of these rings is interposed between one surface of the anode structure and a surface of apertured disks 18 and 19, each disk in turn being in abutment with appropriately formed shoulders 20 and 21 provided by the adjacent pole piece.

Certain features of the electric discharge device of this type employing the permanently magnetized pole pieces or associated structure are disclosed and claimed in my copending patent application Serial No. 447,903, filed June 22, 1942 (now U. S. Letters Patent 2,412,824) and which is assigned to the assignee of this application.

Where it is desired to employ the magnetic pole pieces, either jointly or singly, as supports for the cooperating electrodes, such as a cathode of the discharge device, pole pieces 10 and 11 may be provided respectively with longitudinal openings or channels 22 and 23 which are preferably of circular cross section having ends thereof which terminate in the faces of the magnetic pole pieces 10 and 11.

A cathode, such as a thermionic cathode, is positioned axially and centrally within the opening provided by anode part 8 and may comprise a flanged cylinder 24 coated with a suitable electron emissive material, such as an alkaline earth metal or oxide thereof. Within the cylinder 24 there is provided a cathode heating element 25 the lower terminal of which is electrically connected to an end disk 26, the latter being welded or soldered to cylinder 24. In like manner, the upper part of cylinder 24 is closed by another end disk 27 which is also welded or soldered to cylinder 24. Disk 27, however, may be apertured to permit the extension therethrough of the cathode supporting structure to be described immediately hereinafter.

As a means for supporting the cathode, I may utilize a concentric cable construction disclosed and claimed in copending patent application Serial No. 465,424 of Ralph J. Bondley, filed November 13, 1942 (now U. S. Letters Patent 2,406,277) and which is assigned to the assignee of the present application. This supporting structure may comprise an insulator 28 supported by the inner surface of channel 22 and abutting a copper cylinder 29, and a concentric cable construction comprising an outer tubular conductor 30 and an inner conductor 31 and an interposed tubular insulator 32 affording externally accessible terminals by means of lead-in wires 33 and 34 which are sealed by means of a glass or vitreous seal 35 attached to a flanged cylinder 36, the latter being welded or soldered to the end disk or plate 2. The concentric cable construction extends through the aperture in the end disk 27 of the cathode structure and firmly maintains this structure in axial position by suitable mechanical expedients such as a locking disk or disks **37** and a spacing ring **38** which may be constructed of a suitable temperature resistant metal such as nickel or molybdenum.

In order to extract ultra high frequency energy from the space resonant region or cavity **5**, I may provide output electrode means which may take the form of a loop **39** extending into the chamber **5** and constituting an extension of an inner conductor **40** of a concentric transmission line comprising conductor **40** and an outer tubular conductor **41**.

Fig. 3 represents a plan view of the resonant apertures or slots **9** which are located in the anode part **8**. As concerns the dimensions of the resonant slots or apertures **9**, the longitudinal dimension is preferably made a half wave length, or a multiple thereof, of the electrical oscillations produced by the electrons constituting the electric discharge or space charge between the heating element **25** and anode part **8**. The electrical longitudinal length of the resonant slots **9** must be chosen to compensate for the end effects thereof, and the circumferential dimension c of the slots **9** is chosen with respect to the longitudinal dimension d so that each of these slots constitutes a resonant aperture effecting a concentration across the dimensions of an electric component of the field produced by the oscillating electrons. In other words, the slots are dimensioned so that the distributed inductance and distributed capacitance thereof constitute a tuned circuit. In this manner, each of the slots **9** is selectively responsive to a predetermined frequency of the oscillating electron space charge, and consequently selectively energizes the space resonant region or chamber **5** which, in turn, is also resonant to this frequency.

Considering more particularly the dimensions of the space resonant apertures or slots **9**, one way in which the structure may be viewed is by considering the principal dimension d as being perpendicular to the generally tangential or circumferential electron motion, and in which this dimension is chosen to be a half wave length or $\lambda/2$, where λ is the wave length of the oscillations which it is desired to utilize and at which it is desired to energize the space resonant region **5**. It is to be understood that so far as the dimensions of any one particular slot or aperture are concerned, the aperture may be resonant by having a predetermined relationship or ratio between the dimensions c and d. However, by making the dimension d equal to $\lambda/2$ the dimension c is established or fixed. For very small ratios of c to d, such as a ratio of one-tenth, the dimension c does not affect the resonance characteristics of the aperture in a primary manner.

Upon the application of a voltage, such as a unidirectional voltage between the anode part **8** and the cathode structure, particularly cathode cylinder **24** through outer conductor **30**, there will be established an electric field between the anode part **8** and the cathode cylinder **24**, thereby imparting an oscillatory or helical motion to the electrons. The angular velocity of the electrons constituting the space charge may be considered as determined principally by the strength of the magnetic field which extends longitudinally. By virtue of the interaction of the electric and magnetic fields, the helical motion imparted to the electrons establishes a resultant electric field having radial as well as tangential components, neglecting any longitudinal components incident to the presence of discontinuities at the ends of the space charge region or zone. The space resonant slots **9** having the principal dimension d thereof substantially perpendicular to the tangential components serve as effective means for producing a potential difference across the principal dimension by utilizing this tangential component of the electric field. Inasmuch as these slots are tuned to a particular frequency, means are provided for selecting the chosen or selected frequency produced by the electrons for the energization of the space resonant region **5**.

By virtue of the above described structure of the resonant chamber **5**, there is produced therein a number of circumferential standing electromagnetic waves between the anode part **8** and the inner surface of member **6**, the number of standing wave cycles being equal to half the number of slots. The dimensions are chosen so that the wave pattern is substantially continuous. Due to the symmetry of the structure and the resonant nature of the slots **9**, substantially no discontinuities are present.

In Fig. 4 I have illustrated an alternative form which the resonant slots or apertures may assume. In this arrangement, I have illustrated resonant slots **42** each having a restricted central portion or slit **43** terminated by circular openings **44** and **45**. Each of the entire slots is dimensioned in order to be resonant to a particular frequency.

Figs. 4 and 5 illustrate still further aspects of my invention, and particularly show other forms of aperture arrays which may be employed to derive energy from the oscillating electrons constituting the space charge. These arrays each include a plurality of longitudinal apertures which are resonant to a predetermined frequency and also include circumferential slots or apertures to provide coupling between the longitudinal resonant slots or apertures, thereby causing them to operate in unison or with a predetermined phase relationship which fits the standing wave pattern in the space resonant region. The circumferential slots also serve to utilize to some extent the radial component of the electric field due to the electrons constituting the space charge. These arrays may assume various configurations such as that shown in Fig. 5 wherein the longitudinal and circumferential slots constitute a fret-like configuration.

Referring particularly to Fig. 5, I provide a plurality of circumferentially spaced longitudinal openings **46** interconnected through a common circumferential opening **47**. In this modification, the slots or openings **47** are dimensioned so that contiguous sections thereof are tuned to half wave lengths of the desired oscillations produced by the electron stream.

Fig. 6 represents a still further modification of an array which may be employed in anode part **8** and which constitutes a plurality of alternately spaced longitudinal slots **48** and circumferential slots **49** forming a continuous opening. In like manner, in such an arrangement a longitudinal slot **48** and half portions of adjacent or contiguous circumferential slots **49** may be considered as constituting a tuned section correlated to a predetermined frequency of the electron stream at which it is desired to effect energization of the space resonant region or chamber.

While I have shown and described my invention as applied to a particular system and as embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

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

1. An electric discharge device of the magnetron type including a plurality of electrodes comprising an anode structure and a cathode, said anode structure comprising an annular member of conductive material defining a wave guide capable of supporting standing electromagnetic waves at a predetermined frequency and having a fret-like array of openings facing said cathode comprising a plurality of interconnected longitudinal and circumferential sections tuned to said frequency.

2. An electric discharge device of the magnetron type including a plurality of electrodes comprising an anode structure and a cathode, said anode structure comprising an annular member of conductive material defining a wave guide capable of supporting standing electromagnetic waves at a predetermined frequency and having a fret-like array of openings facing said cathode comprising a plurality of circumferentially spaced longitudinal openings tuned to said frequency and a common interconnecting circumferential opening.

3. An electric discharge device of the magnetron type including a plurality of electrodes comprising an anode structure and a cathode, said anode structure comprising an annular member of conductive material defining a wave guide capable of supporting standing electromagnetic waves at a predetermined frequency and having a continuous fret-like opening facing said cathode and comprising a plurality of alternately spaced circumferential and longitudinal sections tuned to said frequency.

4. An electric discharge device of the magnetron type including a plurality of electrodes comprising an anode structure and a cathode, adapted to have a unidirectional potential impressed therebetween, magnetic means adjacent said electrodes for establishing a magnetic field between said electrodes, said anode structure comprising an annular member of conductive material surrounding said cathode and defining a wave guide of rectangular cross section capable of supporting standing electromagnetic waves at a predetermined frequency and having a fret-like array of openings facing said cathode comprising a plurality of interconnected longitudinal and circumferential sections tuned to said frequency.

5. An electric discharge device of the magnetron type including a plurality of electrodes comprising an anode structure and a cathode, adapted to have a unidirectional potential impressed therebetween, magnetic means adjacent said electrodes for establishing a magnetic field between said electrodes, said anode structure comprising an annular member of conductive material surrounding said cathode and defining a wave guide of rectangular cross section capable of supporting standing electromagnetic waves at a predetermined frequency and having a fret-like array of openings facing said cathode comprising a plurality of circumferentially spaced longitudinal openings tuned to said frequency and a common interconnecting circumferential opening.

6. An electric discharge device of the magnetron type including a plurality of electrodes

comprising an anode structure and a cathode, adapted to have a unidirectional potential impressed therebetween, magnetic means adjacent said electrodes for establishing a magnetic field between said electrodes, said anode structure comprising an annular member of conductive material surrounding said cathode and defining a wave guide of rectangular cross section capable of supporting standing electromagnetic waves at a predetermined frequency and having a continuous fret-like opening facing said cathode and comprising a plurality of alternately spaced circumferential and longitudinal sections tuned to said frequency.

7. An electric discharge device of the magnetron type comprising an anode in the form of a cylindrical wall provided with circumferentially spaced axial slots therein tuned to resonate at a predetermined frequency, means providing a source of electrons within the cylindrical space defined by said anode wall, means adjacent said anode for subjecting said electrons to the action of mutually perpendicular electric and magnetic fields to produce curvilinear motion of said electrons and thereby excite the anode sections between said slots, and a wave guide of generally annular shape with the inner wall thereof formed by said anode wall, said wave guide being tuned to resonate at said predetermined frequency to produce standing electromagnetic waves in said wave guide, said slots being uniformly spaced providing two slots for each cycle of said standing waves around said wave guide whereby the wave pattern in said wave guide is substantially continuous, and alternate anode sections are effectively intercoupled magnetically for stable electrical oscillation at said frequency.

8. An electric discharge device of the magnetron type comprising an anode in the form of a cylindrical wall provided with uniformly and circumferentially spaced axial slots therein tuned to resonate at a predetermined frequency, means providing a source of electrons within the cylindrical space defined by said anode wall, means adjacent said anode for subjecting said electrons to the action of mutually perpendicular electric and magnetic fields to produce curvilinear motion of said electrons and thereby excite said anode slots at said predetermined frequency, and a wave guide of generally annular shape with the inner wall thereof formed by said anode wall, said wave guide being tuned to resonate at said predetermined frequency whereby standing electromagnetic waves are formed therein, the number of said slots being twice the number of cycles of standing waves in said wave guide.

9. An electric discharge device of the magnetron type comprising an anode in the form of a cylindrical wall provided with an even number of uniformly and circumferentially spaced axial slots therein tuned to resonate at a predetermined frequency, means providing a source of electrons within the cylindrical space defined by said anode wall, means adjacent said anode for subjecting said electrons to the action of mutually perpendicular electric and magnetic fields to produce curvilinear motion of said electrons and thereby excite said anode slots at said predetermined frequency, and a wave guide of generally annular shape with the inner wall thereof formed by said anode wall, said wave guide being turned to resonate at said predetermined frequency, the number of cycles of standing waves

produced therein being one half the number of said slots.

10. An electric discharge device of the magnetron type comprising a plurality of electrodes including a cathode and anode structure surrounding said cathode, said anode structure comprising a generally annular member defining a confined annular wave guide tuned to support standing electromagnetic waves at a predetermined resonant frequency and having a plurality of circumferentially and uniformly spaced apertures in the inner wall thereof facing said cathode, said apertures being tuned to resonate at said frequency, the number of said apertures being twice the number of cycles of standing waves produced in said wave guide when said wave guide is excited at said predetermined frequency.

11. An electric discharge device of the magnetron type comprising a plurality of electrodes including a cathode and anode structure surrounding said cathode, said anode structure comprising a generally annular member defining a confined annular wave guide having an even number of circumferentially and uniformly spaced apertures in the inner wall thereof facing said cathode, said apertures being tuned to resonate at a predetermined frequency, and said wave guide being also tuned to resonate at said frequency, the number of cycles of standing waves produced therein being one half the number of said apertures.

ELMER D. McARTHUR.

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