

Oct. 1, 1957

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MAGNETRON OSCILLATOR

2,808,538

Filed Oct. 2, 1952

FIG. 3

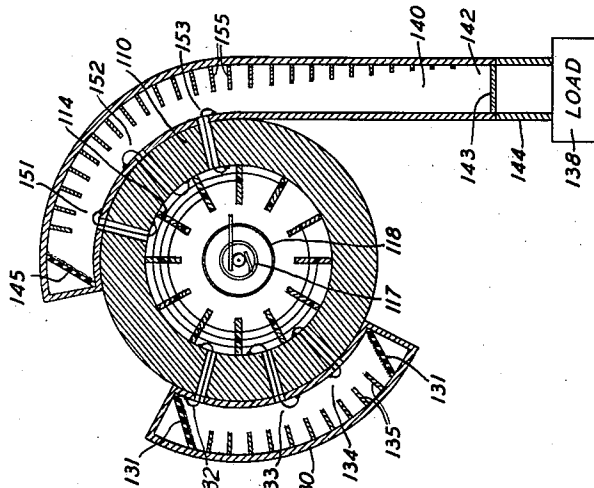


FIG. 2

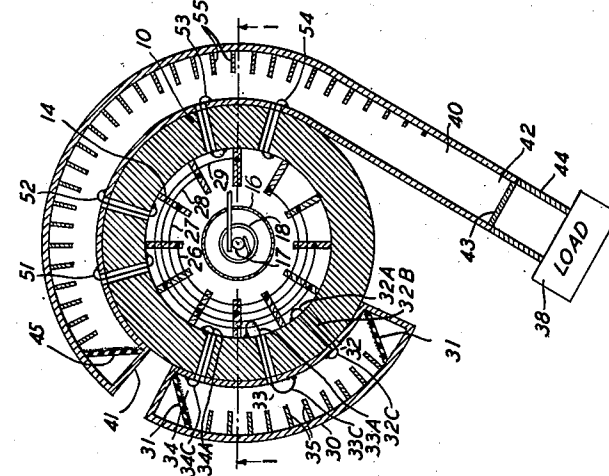
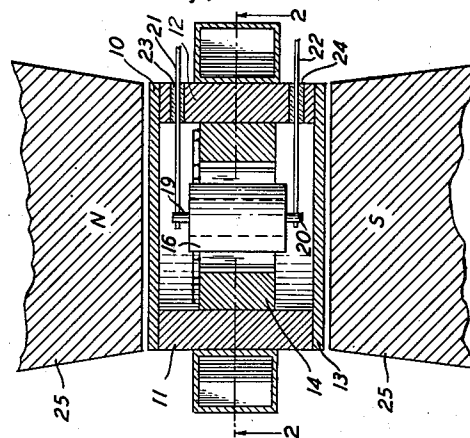


FIG. 1



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2,808,538

MAGNETRON OSCILLATOR

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Application October 2, 1952, Serial No. 312,770

10 Claims. (Cl. 315—39.3)

This invention relates to magnetron oscillators.

The primary object of the present invention is to reduce the effects of load variations on the operating frequency of such oscillators.

It has been characteristic of magnetron oscillators known hitherto that the frequency of the oscillations is to a considerable degree dependent on the load so that variations in the load tend to shift the oscillatory frequency, an effect known as "pulling." Such frequency shifting is generally undesirable, particularly when it results in reduced efficiency as where the magnetron oscillator is most advantageously operated at a particular fixed frequency. Various arrangements have been devised hitherto for minimizing pulling, but these have generally necessitated the interposition of a buffer element, such as a buffer amplifier, for isolating the load from the resonant chamber wherein the oscillations are generated. It would obviously be preferable to minimize pulling in a more direct fashion.

To this end, there is utilized a magnetron oscillator which is operated in a mode in which useful electron interaction takes place only with an anode potential wave which circulates in a specific direction relative to that of electron flow. It can be seen that operation of this kind excludes the two modes in which adjacent resonators are in phase and π radians out of phase. Operation in either of these two modes corresponds to interaction with a standing wave pattern as is characteristic of operation in accordance with the present invention. Then, oscillatory energy is abstracted from the resonant chamber by way of directive coupling for propagation along a wave guiding path to the load at one end of the path, the other end of which is closed by a reflectionless termination. It is characteristic of this arrangement that energy reflected from the load as a result of mismatches caused by load variations is returned along the wave guiding path and either is dissipated in the reflectionless termination at the closed end of the wave guiding path or is coupled back into the resonant chamber for circulation therearound until dissipated in a direction opposite to that of the anode potential wave associated with the oscillations in the resonant chamber and hence unsuitable for interaction with the electron flow. As a result of the isolation secured in this way between the load and the resonant chamber, the operating frequency of the magnetron oscillator is little affected by load variations. In preferred embodiments, it is generally advantageous to resort to expedients for minimizing modes other than the one desired for interaction with the electron flow.

The invention will be more fully understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a vertical cross section taken along the line 1—1 of Fig. 2 of a magnetron, in accordance with the invention, which is designed for operation with a phase

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difference of $\pi/2$ radians between adjacent resonant cavities;

Fig. 2 is a transverse cross section of the magnetron shown in Fig. 1 taken along line 2—2 of Fig. 1; and

Fig. 3 is a view similar to that shown in Fig. 2 for a magnetron, in accordance with the invention, designed for operation with a phase difference of $2\pi/3$ radians between adjacent resonant cavities.

With reference now to the drawings, the magnetron illustrated by way of example in Figs. 1 and 2 comprises an evacuated enclosure or envelope 10 made of a non-magnetic conductive material, such as copper, and having an annular cylindrical portion 11 which is covered by end portions 12 and 13 hermetically soldered in place to form a resonant chamber. A plurality of radially disposed plates or vanes 14 extend from the inner surface of the cylindrical portion 11 and regularly spaced therearound for forming a multisegment anode. Extending axially along the center of the interior of the cylindrical portion 11 is an elongated cylindrical cathode 16, which preferably is of a thermionic indirectly heated oxide-coated type. The cathode 16 is provided with an internal heater 17 and an outer conductive sleeve 18 which is covered with a thermionically emitting oxide coating. A pair of conductors 19 and 20 supply the heating potentials to the heater. The conductor 19 is also connected electrically to the conductive sleeve 18 while the conductor 20 is insulated from this sleeve. The conductor 19 is adapted to be maintained at a high negative voltage with respect to the conductive envelope 10 whereby a strong radial D.-C. electric field is set up between the cathode 16 and the multisegment anode. The cathode 16 is supported by a pair of lead-in conductors 21 and 22 welded respectively, to the conductors 19 and 20. These lead-in conductors pass through glass seals 23 and 24, respectively, in the upper and lower ends of the cylindrical portion 11 of the envelope.

For operation, the tube is placed between suitable magnetic poles 25 which create a longitudinal magnetic field extending parallel to the axis of the cathode 16 and perpendicular to the radial D.-C. electric field set up between the cathode and the multisegment anode formed by the vanes 14. Then, when the tube is energized so that electron flow circulates in the interaction space between the cathode 16 and the multisegment anode, oscillations are set up in the regions between each pair of adjacent vanes which form a succession of resonant cavities. There has been described up to this point a magnetron of the kind well known to the art. Such a magnetron is capable of various oscillating modes, which are dependent on the strength of the magnetic field, the strength of the applied D.-C. electric field, and the number and geometry of the various resonant cavities. Such a system of resonators may oscillate in a number of different modes in each of which the oscillations in adjacent cavities, and thus the fields across adjacent gaps between vanes, bear a definite phase relationship. The sequence of anode segment potentials at any instant contains n complete cycles in one traversal of the cylindrical anode. In general, these anode potential waves may be standing waves or waves traveling around the anode in either direction. It is in accordance with the invention to operate the magnetron in a mode in which the electron flow will interact favorably only with a wave traveling in one particular direction, preferably the same as that of the electron flow.

It is generally the practice to limit the oscillations to a particular mode for frequency stability. Most often, the so-called π mode is preferred in which the anode potential wave is such that there is a phase difference of π radians between adjacent anode segments. However, such a

mode is a standing wave mode and undesirable in the present instance. The magnetron shown in Fig. 1 is, by way of example, designed for operation in $\pi/2$ mode in which the phase difference between adjacent anode segments is $\pi/2$ radians. The magnetron shown in Fig. 3 is on the other hand, designed for operation in the $2\pi/3$ mode. However, in each instance the operation is in a traveling wave mode.

Various expedients are known for mode suppression. Preference can, of course, be shown to a particular mode by suitable choice of the strength of the radial electric and axial magnetic fields and the number and geometry of the anode segments. The general design principles applicable are described in an article entitled "The magnetron as a generator of centimeter waves," by J. B. Fisk, H. D. Hagstrum and P. L. Hartman, and published in the Bell System Technical Journal, April 1946.

In the tube shown in Figs. 1 and 2, two expedients are used to restrict operation to the desired $\pi/2$ mode. First, resort is had to strapping for separating the modes and facilitating oscillation in the $\pi/2$ mode alone. To this end, every fourth anode segment is connected together. For the magnetron here illustrated which employs twelve anode segments, four straps 26, 27, 28 and 29 are employed, each of which is connected to three anode segments. In the afore-mentioned Bell System Technical Journal article there is set forth the general design considerations applicable to such strapping.

In addition to strapping, in accordance with one aspect of the invention resort is had to suppression of the undesired modes by "swamping." To this end, a section of evacuated hollow rectangular wave guide 30 which is closed at both ends is wrapped around a portion of the envelope, preferably with the long dimension of the wave guide in contact with the external wall of the envelope. A tapered dielectric block 31 which is coated with lossy material is positioned at each end of the wave guide 30 to absorb incident wave energy. For the suppression of the undesired modes of oscillation, the swamping wave guide is coupled to the tube strongly at the undesired modes of oscillation while only loosely at the desired mode. To this end, multiple coupling connections are made between the swamping wave guide and resonant cavities of the tube. This loading tends to prevent all but the desired mode from being initiated. In this embodiment where all but the $\pi/2$ mode are to be suppressed three coupling connections 32, 33 and 34 are provided between three successive cavities and the swamping wave guide 30. Each coupling connection includes a cavity coupling loop and a wave guide coupling loop, the two being interconnected by a conductor. For example, coupling connection 32 comprises the cavity loop 32A, the conductor 32B and the guide loop 32C. One end of each cavity of each coupling loop is electrically connected to the inner wall of the envelope 10 and the other end of each cavity coupling loop is connected to a conductor shown which extends through openings in the walls on the envelope 10 and the wave guide 30 and connects to an end of the wave guide coupling loop in the interior of the wave guide, the opposite end of which is connected electrically to the wall of the wave guide 30. The two cavity loops 32A and 34A are in the same sense as their corresponding guide loops 32C and 34C, while the cavity loop 33A is in the reverse sense as its corresponding guide loop 33C whereby there is introduced a phase reversal. Moreover, the intermediate connection 33 is adjusted to provide twice the coupling of each of connections 32 and 34. To this end the loops 33A and 33C associated therewith will be of larger diameter than the loops associated with connections 32 and 34. Additionally, the wave guide 30 is loaded, for example by fins or corrugations 35 extending transversely from the wave guide side wall opposite that in contact with the envelope 10, to reduce the velocity of wave propagation in the guide 30 sufficiently that the guide coupling loops 32C, 33C and 34C

will be a quarter of a guide wavelength apart at the desired mode of oscillation. Analysis of the effect of the wave guide 30 will show that the coupling to this wave guide will be a minimum to the desired $\pi/2$ mode of oscillation. To this end, wave energy of the desired mode of propagation supplied by the three coupling connections to the guide 30 tends to cancel out so that there is no net energy of this mode supplied to the wave guide. At the other likely modes of oscillation, however, this cancellation does not take place and there tends to be a net delivery of wave energy to the wave guide sufficient to inhibit the building up of oscillations of undesired modes. In this way, selective mode suppression is achieved.

Additionally, it is in accordance with the invention to abstract the oscillatory energy of the desired frequency for transmission to a utilization circuit or load 38 by way of a directional coupler. In simple terms, a directional coupler is a coupling arrangement whereby a wave propagating in a primary path excites in a secondary path a wave propagating in one direction only. The general principles of directive coupling are found described in an article entitled "Directive Couplers in Wave Guides" by M. Surdin published in the Journal of the Institution of Electrical Engineers, volume 93, part IIIA, pages 725 through 736. To this end, the desired oscillatory energy in the tube is supplied by means of a directional coupling arrangement into an evacuated hollow wave guide 40, preferably of rectangular cross section, and having one closed end 41 and an opposite end 42 which is sealed off to the atmosphere by a glass window 43 which, however, permits abstraction therethrough of oscillatory energy. At this opposite end 42, the wave guide is connected to a wave guide 44 through which the oscillatory energy is led to the external utilization device 38, which constitutes the load. At the closed end 41 of the guide 40, there is inserted a tapered dielectric block 45 coated with lossy material for serving as a broad band reflectionless termination. The wave guide 40 is wrapped around a portion of the tube envelope 10 preferably with one of its side walls of long dimension in contact with the envelope. To achieve directive coupling between the wave guide 40 and the tube for the oscillatory energy of $\pi/2$ mode, four connections 51, 52, 53 and 54 of equal coupling strength are provided which, for example, are of the kind used in the swamping wave guide 30. Each has its cavity coupling loop and guide coupling loop wound in the same sense. However, for directive coupling to the $\pi/2$ mode in the tube, the coupling connections are spaced apart a quarter, a half, and a quarter the guide wavelength. Since adjacent cavity resonators in the tube are $\pi/2$ radians apart, the desired relationships are achieved by associating coupling connections 51 and 52 and 53 and 54 with adjacent cavities, while leaving uncoupled one cavity between connections 53 and 54, and by then loading the wave guide 40 along this coupling region by transverse corrugations 55 to provide a guide wavelength in this coupling region such that the distance along the wave guide corresponding to the separation of adjacent cavities in the tube is a quarter a guide wavelength. Beyond this coupling region, these corrugations 55 taper off in length for effecting a transition to the smooth rectangular wave guide at the end 42. An analysis of this coupling arrangement made in the afore mentioned Surdin article shows that this arrangement results in co-directive coupling i. e. waves circulating in a clockwise direction in the tube will induce a wave propagating only in a clockwise direction in the guide 40, and, reciprocally waves propagating in a counter-clockwise direction in the guide 40 will set up a wave traveling counter-clockwise in the resonant chamber. Accordingly, for the oscillator shown the strengths of the radial electric and axial magnetic fields and the geometry of the resonators are chosen so that favorable interaction takes place only with a wave traveling clock-

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wise in the tube to provide a clockwise propagation of oscillatory energy in the guide 40.

The operation is in most respects similar to that of a conventional magnetron oscillator. Oscillations are set up in the resonant chamber characteristic of the non-degenerative $\pi/2$ mode. The various expedients described serve to suppress oscillations of all other modes. Oscillatory energy of the mode is abstracted from the tube by the several coupling connections for propagation along the wave guide 40 only in the direction towards the load 38. Energy reflected from the load 38 is either dissipated in termination 45 or else coupled back into the tube in a direction for travel only in a non-synchronous clockwise direction until dissipated and, accordingly, has little effect on the desired oscillatory mode.

Fig. 3 shows as another illustrative embodiment a magnetron oscillator designed for operation with a phase difference of $2\pi/3$ radians between adjacent cavities. In the interest of simplicity like elements in the two magnetron oscillators illustrated have been designated by reference characters which differ by one hundred. Accordingly, the envelope designated by reference numeral 10 in Figs. 1 and 2 is designated by reference numeral 110 in Fig. 3. The other designations are made in corresponding fashion. To accent the desired $2\pi/3$ mode, it is advantageous in this instance to strap together every third vane 114 in accordance with well accepted principles. Additionally, for mode suppression, there is employed a swamping wave-guide section 130 which is coupled to three successive cavities by three connections 132, 133 and 134 of equal coupling strength but of which coupling connections 132 and 134 have their cavity and guide loops wound in the same sense, while those of coupling connection 133 are wound in an opposite sense to achieve a phase reversal. Additionally, the wave guide 130 is loaded by transverse corrugations 135 to provide a guide wavelength for the $2\pi/3$ mode of oscillations which is twice the separation between adjacent coupling connections in the wave guide 130, so that adjacent coupling connections are separated by one half a guide wavelength. Moreover, to effect the desired directional properties, the output wave guide 140 is provided with three connections 151, 152 and 153 of equal coupling strength which are associated with three successive cavities of the tube. The center coupling connection 152 has its cavity and guide loops reversed in sense while those of the coupling connections 151 and 153 are in the same sense. Additionally, the wave guide 140 is loaded along the coupling region by transverse corrugation 155 designed to provide a guide wavelength to the desired $2\pi/3$ mode of oscillatory energy such that the coupling connections 151, 152 and 153 are spaced apart in the guide one third this wavelength. As a consequence there results anti-directional coupling between the tube and the wave guide 140. Moreover, the strengths of the radial electric and axial magnetic fields and geometry of the resonators are adjusted for electron flow interaction with this desired mode. Thereafter, the operation of this oscillator is similar to that described for the oscillator shown in Figs. 1 and 2.

It should be evident from the foregoing description that the two embodiments described are merely illustrative of the general principles of the invention. Various other embodiments, for example, designed for operation at other traveling wave oscillatory modes or utilizing different forms of directive coupling, resonant cavities, and mode suppression arrangements, can be devised by one skilled in this art without departing from the spirit and scope of this invention.

What is claimed is:

1. In combination, an electron discharge device comprising a cathode for providing electron flow and an anode spaced around said cathode in electron collecting relation, the region between said cathode and anode forming an interaction space, means for imparting to the electron flow in said space a circular component for creating

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radio frequency waves circulating in said space in a particular direction for interaction with the electron flow, means for selectively suppressing radio frequency waves traveling in the interaction space in a direction opposite to said particular direction, a hollow wave guide extending around a portion of said device terminated at one end to be substantially reflectionless and open to wave energy at the opposite end for abstraction of energy, and directional coupling means comprising a series of spaced coupling connections between said hollow wave guide and anode for selectively coupling the radio frequency waves circulating in the interaction space in said particular direction into said wave guide for travel therealong towards the open end and for selectively coupling radio frequency energy reflected from said open end back into said space for travel therearound in a direction opposite to said particular direction.

2. In combination, an electron discharge device comprising a cathode for providing electron flow and an anode assembly comprising a plurality of cavity resonators spaced around said cathode, the electron flow between said cathode and anode assembly giving rise to radio frequency oscillations in the interaction space between the cathode and anode assembly, means coupled to the cavity resonators for constraining the device to operate in a traveling wave mode of oscillation, a hollow wave guide extending around said device having one end terminated to be substantially reflectionless and an opposite end for abstracting oscillatory energy, and means directionally coupling said wave guide and said device for abstracting energy from said device for selective propagation along said wave guide in the direction of said opposite end.

3. In combination, an electron discharge device comprising a cathode for providing electron flow and an anode disposed circumferentially around said cathode in electron collecting relationship therewith, the region between said cathode and anode forming an interaction space, means for producing a magnetic field transverse to the discharge path between said cathode and anode for imparting a circular component to the electron flow in the interaction space, a hollow wave guide extending around a portion of said anode, the hollow wave guide having one end through which oscillatory energy can be abstracted and one end which is made substantially reflectionless, and directional coupling means comprising a series of spaced connections for coupling together the discharge device and the hollow wave guide.

4. In combination, an electron discharge device comprising a cathode and an anode disposed around said cathode in electron collecting relation therewith, the region between said cathode and anode forming an interaction space, means adjacent said cathode for forming a magnetic field transverse to the discharge path between said cathode and anode for imparting a circumferential component to electron flow in said interaction space, means forming a wave guiding path having an end open to wave energy through which energy is abstracted for utilization and an end closed to wave energy, and means coupled to the device for coupling energy out of said interaction space for propagation in the direction of said open end and coupling energy reflected from said open end into said interaction space for propagation in a direction opposite to that of said circumferential component of electron flow.

5. In combination, an electron discharge device comprising a cathode and an anode assembly having a plurality of cavity resonators surrounding said cathode, the region between said cathode and anode structure forming an interaction space, means providing magnetic and electrostatic fields in the interspace between the cathode and anode for establishing a traveling wave mode of oscillation at a particular frequency in the electron discharge device, means coupled to the cavity resonators for inhibiting modes of oscillation at frequencies other than said particular frequency, a wave guide having one end

terminated to be substantially reflectionless and an opposite end for abstracting oscillatory energy, and a directional coupling means between said device and the wave guide for abstracting energy of the particular frequency from said device for supplying said wave guide for propagation in the direction of said opposite end.

6. In combination, an electron discharge device comprising a cathode for providing electron flow and an anode spaced around said cathode in electron collecting relationship, the region between said cathode and anode forming an interaction space, means for imparting to the electron flow in said space a circular component for creating radio frequency waves circulating in said space in a particular direction for interaction with the electron flow, a hollow wave guide extending around a portion of said device and which is terminated at one end to be substantially reflectionless and at the opposite end open to wave energy for abstraction of energy, directional coupling means comprising a series of coupling connections in said hollow wave guide and anode spaced for selectively coupling the radio frequency waves circulating in said interaction space in said particular direction into said wave guide for travel therealong towards the open end and for selectively coupling radio frequency energy reflected from said open end back into said interaction space for travel therearound in a direction opposite to said particular direction.

7. In combination, an electron discharge structure comprising a cathode for providing electron flow, an anode assembly comprising a plurality of cavity resonators surrounding said cathode, said cathode and anode assembly to be exposed to a magnetic field substantially perpendicular to the discharge path between said cathode and anode assembly, the anode assembly, the strength of the magnetic field and the potential difference to be applied between the cathode and anode assembly constraining the electron discharge device to operate in a traveling wave mode of oscillation, a wave guide extending around a portion of said anode assembly having one substantially reflectionless terminated end and an opposite end for abstracting oscillatory energy, and directional coupling means linking said wave guide and a plurality of cavity resonators of said anode assembly at spaced points whereby the oscillatory energy abstracted from the electron discharge structure propagate in said wave guide towards said opposite end.

8. In combination, an electron discharge device comprising a cathode for forming electron flow and a multi-segment anode assembly including a plurality of cavity resonators disposed around said cathode in electron collecting relationship, the space between said cathode and anode assembly forming an interaction space wherein are set up oscillatory waves, means for constraining the oscillations to a particular frequency characteristic of a traveling wave mode comprising a section of hollow wave guide closed at both ends and disposed around a portion of said

device, lossy means in said wave guide for dissipating energy traveling therethrough, multiple connections between the wave guide and the cavity resonators of said device for selectively abstracting from the device wave energy of frequencies other than said particular frequency, a hollow wave guide section disposed around a different portion of the device having one end close to wave energy and an opposite end open to wave energy through which oscillatory energy of the particular frequency can be abstracted for utilization, and multiple connections between said last-mentioned wave guide and the cavity resonators of said device for directionally coupling energy of said particular frequency from said device into said last-mentioned wave guide for selective propagation towards its opposite end open to wave energy.

9. In combination, an electron discharge device comprising a cathode for forming electron flow and a multi-segment anode assembly disposed around said cathode in electron collecting relationship, the space between said cathode and anode assembly forming an interaction space wherein are set up oscillatory waves, means for constraining the oscillations to a particular frequency comprising a section of wave guide terminated to be substantially reflectionless at both ends and extending around a portion of said device, multiple connections coupling the wave guide to the device for abstracting from said device wave energy of frequencies other than said particular frequency, and means for abstracting wave energy of said particular frequency from the electron discharge device.

10. In combination, an electron discharge device comprising a cathode for forming electron flow and a multi-segment anode assembly disposed around cathode in electron collecting relationship, the space between said cathode and anode assembly forming an interaction space wherein are set up oscillatory waves, means for constraining the oscillations to a particular frequency comprising a section of hollow wave guide closed at both ends disposed around a portion of said device, lossy means in said wave guide for dissipating the wave energy therein, and multiple connections between said wave guide and said device for selectively abstracting from said device wave energy of frequencies other than said particular frequency, and means for abstracting wave energy of said particular frequency from the electron discharge device.

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