

Aug. 30, 1960

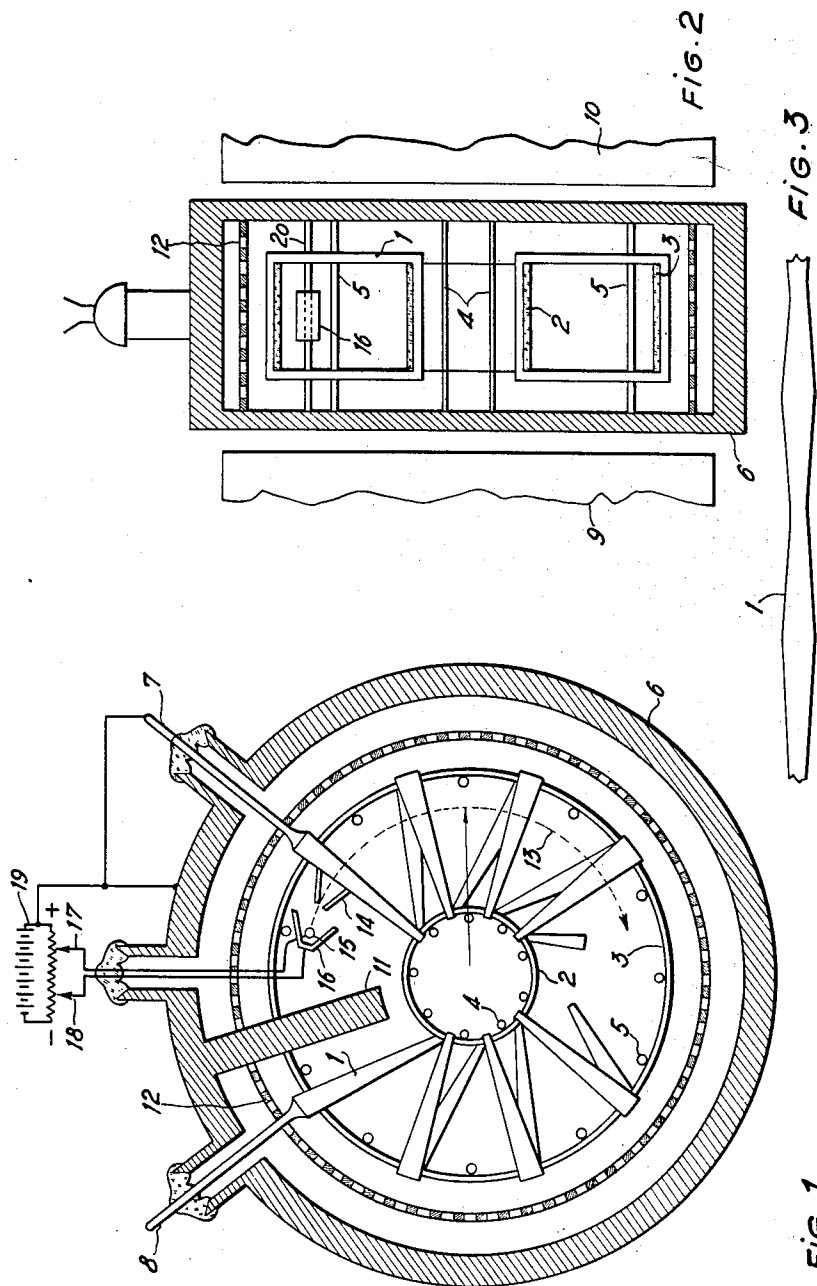
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2,951,173

TRAVELING WAVE TUBE OSCILLATORS

Original Filed July 20, 1954

4 Sheets-Sheet 1



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4 Sheets-Sheet 2

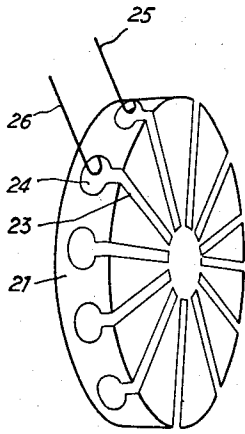


FIG. 4

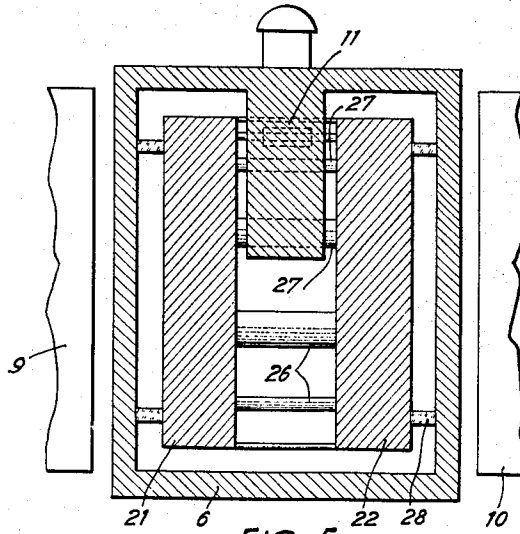


FIG. 5

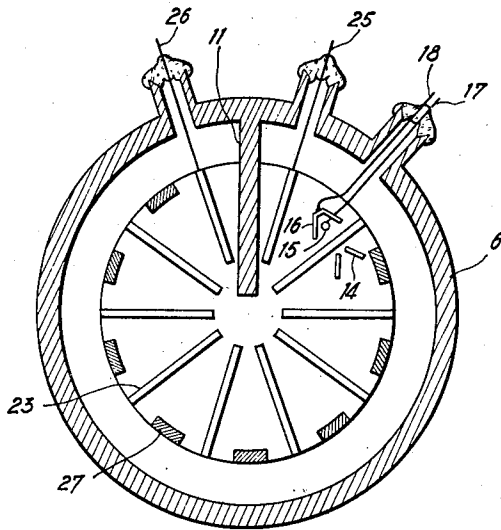


FIG. 6

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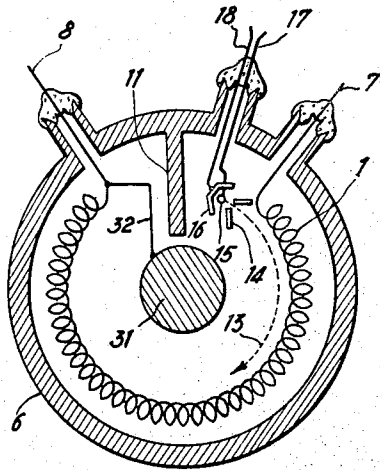


FIG. 7

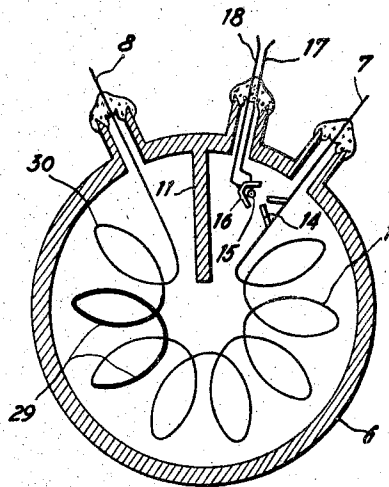


FIG. 8

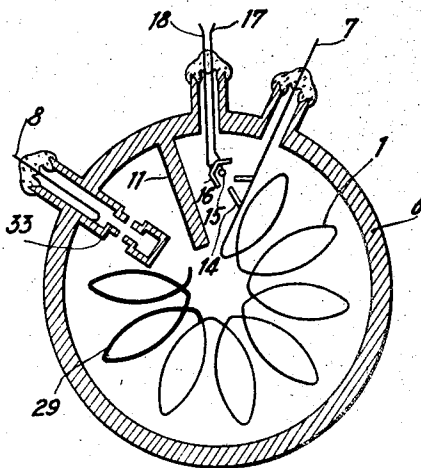


FIG. 9

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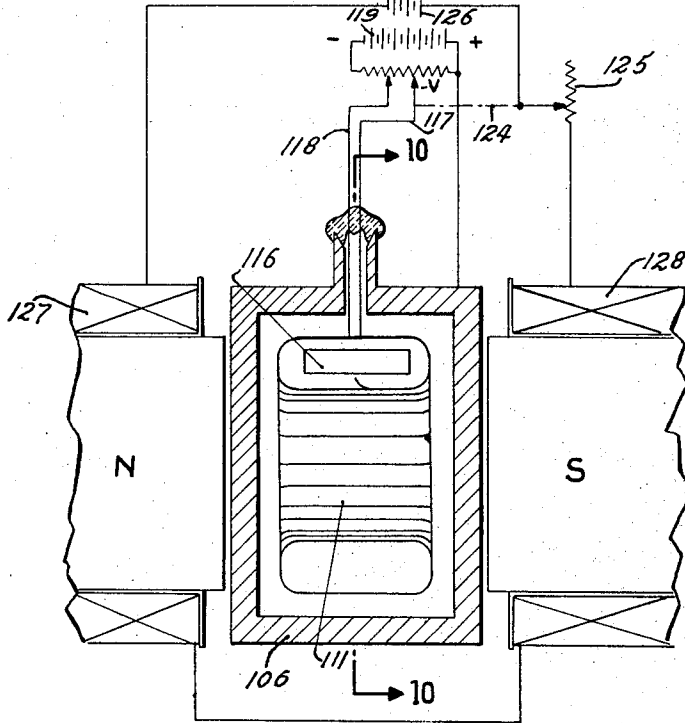


Fig 11

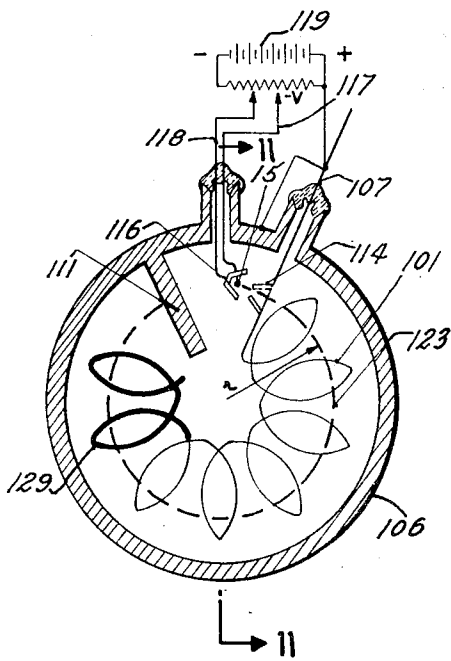


Fig 10

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1

2,951,173

TRAVELING WAVE TUBE OSCILLATORS

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Filed Mar. 24, 1958, Ser. No. 723,467

Claims priority, application France Nov. 25, 1947

10 Claims. (Cl. 315—3.5)

This application is a continuation application of our application Serial No. 444,558, filed July 20, 1954, now abandoned, which in turn was a continuation-in-part application of our application Serial No. 59,364, filed November 10, 1948, also abandoned.

The present invention relates to a new type of backward wave oscillator, operating by interaction of a backward space harmonic with an electron beam propagating in an interaction space which is free of transverse electric field, as disclosed in the copending application Serial No. 281,347, filed by B. Epsztein on April 9, 1952, assigned to the assignee of the present invention.

The tube according to the present invention generally comprises, within an evacuated envelope, an interaction space free of electric field and limited by a circularly bent structure, made of a conductive material and comprising an ultra-high-frequency delay line, the structure being brought to a predetermined potential. Within this space is applied, in the axial direction of the structure, a uniform, time-constant magnetic field, while an electron beam is injected in this space in a plane perpendicular to this direction, the velocity of the beam, which is perpendicular to this axis, and expressed in volts, being equal to the potential of the structure concerned; thus the beam describes under the action of the magnetic field a circular trajectory about the line axis. Electromagnetic energy is caused to propagate along the delay line with an angular phase velocity equal to the angular velocity of the beam. This results in the amplification of the ultra-high-frequency energy and, under certain conditions, in the generation of oscillations.

An object of the invention is such an oscillator, occupying, however, less space as compared to the linear embodiment disclosed in said Epsztein application, for similar performance.

A further object of the invention is an oscillator, operating with smaller values of anode potential and magnetic field, than a circular M-type backward wave oscillator, mentioned in said Epsztein application, for similar diameter and performance.

The present invention is a further development of our invention disclosed in copending application Serial No. 727,513, filed of even date herewith, entitled "Traveling Wave Tubes," which is a continuation-in-part of our application Serial No. 444,558, filed July 20, 1954, now abandoned, which in turn was a continuation-in-part application of our aforementioned application Serial No. 59,364, filed November 10, 1948, now abandoned. The invention disclosed in said copending application provides a tube comprising, inside an evacuated envelope, an interaction space free of electric field and limited by a circularly bent structure, made of a conductive material and comprising an ultra-high-frequency delay line, the structure being brought to a predetermined potential. Within this space is applied, in the direction of the structure axis, a uniform, time-constant magnetic field, while an electron beam is injected in this space

2

in a plane perpendicular to this direction, the velocity of the beam, which is perpendicular to this axis, expressed in volts, being equal to the potential of the structure concerned; thus the beam describes under the action of the magnetic field a circular trajectory about the tube axis.

According to the present invention, a backward wave oscillator of the type just described comprises a delay line having propagation characteristics able to transmit in the desired bandwidth a wave having a strong backward space harmonic, i.e., a harmonic traveling in a direction opposite to that of the ultra-high-frequency energy, the angular beam velocity being made equal to angular phase velocity of this harmonic, an ultra-high-frequency output coupled to the beam source side of this line, and attenuating means associated with this line at a point thereof remote from said output.

The invention will be best understood from the following description, reference being made to the accompanying drawings wherein:

Figure 1 shows a cross section of a first embodiment of the invention, used as an amplifier;

Figure 2 shows a longitudinal view of the embodiment of Figure 1;

Figure 3 illustrates the shape of the helical conductor of Figure 1;

Figure 4 shows in perspective a second embodiment of the present invention also used as an amplifier;

Figure 5 shows a longitudinal cross section of the embodiment according to Figure 4;

Figure 6 shows a transverse cross section of the embodiment according to Figure 4;

Figure 7 shows a cross section of a third embodiment of the invention, used as an amplifier;

Figures 8 and 9 show cross sections of further embodiments of a tube similar to Figure 1;

Figure 10 shows a cross section taken along line 10—10 of Figure 11; and

Figure 11 shows an axial cross section taken along line 11—11 of Figure 10 of an embodiment of backward wave oscillator according to the present invention.

The tube shown in Figures 1 to 3 is designed for operation as an amplifier; the space, free of electric field, in which the beam propagates, is included in a helix 1. This helix is wound circularly over two coaxial insulating rings 2 and 3 which are supported, respectively, by cross rods 4 and 5 fastened to the upper and lower covering plates of the vacuum tight cylindrical envelope 6. The input and output ends of the helix are connected, respectively, to the ultra-high-frequency conductors 7 and 8, which are, respectively, the input and output for the ultra-high-frequency energy. The envelope 6 is placed in a magnetic field directed along its axis of symmetry and supplied by pole pieces 9 and 10. The helix is wound as a flat tape; Figure 3 shows one of its turns unrolled; the turns are of rectangular cross section, the small side of the rectangle being oriented in the direction of the lines of force of the magnetic field as best seen in Figure 2. Between input 7 and output 8 is placed an uncoupling screen 11 connected to the envelope 6, the helix assembly being surrounded by a grid 12 also connected to the envelope 6. An electron gun is placed ahead of the helix input; according to the present invention, this gun is located in the vicinity of the helix periphery, as shown in Figure 1, so that the beam 13 of electrons indicated in Figure 1 by the dashed line travels nearer to this periphery than to the center of the helix. This gun consists of an anode 14 connected to the helix 1 and hence brought to the potential of the latter, of a cathode 15 and of a Wehnelt electrode 16; the two latter electrodes 15 and 16 are carried by an insulating rod 20 and brought to suitable negative potentials with respect

3

to the anode, by means of conductors 17 and 18 connected to appropriate tops of the D.C. power supply or source 19; the positive pole of the latter is connected to the envelope 6 and to the helix 1 by means of conductor 7.

Operation.—The arrangement of the embodiment of Figures 1 through 3 operates as follows:

Let B be the induction of the magnetic field prevailing in the tube due to pole pieces 9 and 10 and V the potential difference between the helix 1 and cathode 15. The electron beam, accelerated by the potential V of the anode 14, enters the helix with a velocity

$$v_{\text{cm./sec.}} = 6.10^7 \sqrt{V} \text{ volts} \quad (1)$$

Conventionally, this velocity v shall hereinafter be expressed by the potential V (volts).

In accordance with Larmor's law, this beam describes a circle in the space free of the electric field inside the helix, with an angular velocity:

$$\omega = \frac{e}{m} \cdot B \quad (2)$$

where e and m are, respectively, the charge and the mass of an electron.

If the beam is to describe a circular trajectory centered on the tube axis and of a given radius r , the angular velocity

$$\frac{v}{r}$$

must be equal to ω , and hence V and B must be connected by the equation:

$$\frac{6.10^7 \sqrt{V}}{r} = \frac{e}{m} B \quad (3)$$

There will arise an interaction between the electron beam and the ultra-high-frequency energy fed through the input 7 and propagating within the helix 1, if the angular phase velocity of the energy, determined by the delaying properties of the helix 1, is equal to ω .

Applicants have established that, if the electron beam is to yield energy to the alternating electromagnetic field, it is necessary that the electron gun be disposed substantially nearer to the outer periphery of the helix than to its central part. This is why the gun 14, 15, 16 has been placed next to the ring 3, as indicated in Figure 1.

The grid 12, which is made, for instance, of molybdenum, is for stopping those electrons which, traveling towards the outer part of the helix 1, might run out of the latter.

The fact that the helix 1 is of flat cross section, with the small axis of the cross section thereof pointing in the direction of the magnetic field, makes it possible to reduce the magnitude of the radial component of the ultra-high-frequency field inside the helix; this component is detrimental since it results in imparting energy to the electrons taken off the ultra-high-frequency field, which in turn results in a decrease in the efficiency.

Assuming the velocity v of the electrons to be $\frac{1}{20}$ of the velocity of the light ($V=625$ volts) and assuming further that $r=3$ cm., it may be calculated from Formulae 1, 2 and 3 that the value for the magnetic field must be $B=28$ gauss. It is seen from this example that the source 19 must supply a relatively low voltage and, furthermore, that the magnet 9, 10 may be a permanent magnet.

In the embodiment represented by Figures 4 to 6, the space free of electric field is included between two parallel identical disks 21 and 22; one of these disks is shown in perspective in Figure 4. Each disk 21 and 22, preferably of copper, displays a number of radial slots 23 which communicate with cavities 24, also radial. The assembly formed by these cavities 24 and slots 23 constitutes a delay line. In one of these cavities, an ultra-high-frequency electromagnetic wave is excited by means

4

of the loop 25, the energy being collected at the output also by means of a loop 26. The two disks 21, 22 (Figure 5) are connected by cross arms 27 made of conducting metal plate, the latter both ensuring the rigidity of the assembly and enabling the two disks to be brought to the same potential, so that the space between the disks is screened off from the action of any D.C. electric field.

In this space is disposed a gun 14, 15, 16 which is identical with that of Figure 1 and is likewise placed nearer to the periphery than to the center of the disks 21 and 22.

The disks 21 and 22 are clamped by rings 28 against the wall of the envelope 6 on which is also secured the collector 11, the latter extending both between the disks 21 and 22 and between the input 25 and output 26. The tube structure, moreover, is the same as that of Figure 1, operation being analogous thereto.

In the embodiment schematically shown in Figure 7, the fieldless space in which the beam propagates is included between a delay line 1, on the one hand, shown again in the form, for example, of a helix though any other type such as a vane-type delay line or one made of a sequence of cavities may also be used, and a coaxial cylindrical electrode 31, on the other, arranged centrally in the tube. Through the connection 32, the line 1 is brought to the potential of the electrode 31. Connection 32 may alternatively be replaced by an equivalent exterior to the tube or by separately feeding the two electrodes 1 and 31. Unlike Figure 1, the beam 13 does not travel inside but outside the helix. The gun 14, 15, 16 is arranged nearer to the helix 1 than to the electrode 31. Furthermore, like references again denote like elements, and the tube of Figure 7 operates as in the case of Figure 1.

Figure 8 represents a modification of the tube of Figure 1, but this modification can, of course, be applied to the other embodiments of the invention. At the extremity of the helix, the turns 29 are coated with a substance that fully absorbs the ultra-high-frequency wave; as a result thereof, there arises along the portion of space inside the turns 29 a drift space for the electrons of the beam 12. The outermost section 30 of the helix 1 is, therefore, coupled only electronically to the section of the helix preceding the attenuator 29; the outermost section 30 may, therefore, be regarded as a distinct output circuit connected to the output 8; it is integral with sections 1 and 29 only for constructive convenience.

In Figure 9 the output circuit is a resonant cavity 33. The invention is not limited to using the described tube as an amplifier; it may be used also as an oscillator. To achieve this, one simply has either to eliminate the collector 11 so that the electrons be re-fed to the input of the delay line, or to set up an outer feedback coupling between the output 8 and the input 7, or use the tube as a backward wave oscillator to be described more fully hereinafter.

Certain prior art devices are known which may superficially resemble the present application which, however, are clearly distinguishable therefrom on the following grounds.

United States Patent 2,652,270 to R. Kompfner relates to rectilinear wave traveling tubes in which a beam propagates in an equipotential space, inside a rectilinear helix, interacting with the wave which propagates in the helix. The tube according to the present invention differs from the tube covered by this Kompfner patent by the following features:

- (a) The presence of the magnetic field, perpendicular to the plane of initial velocity of the beam;
- (b) The circular trajectory of the beam, as a result of this field; and
- (c) The general curved or circular structure of the tube. It has the advantage that it occupies less space

than the rectilinear structures affording comparable performance. In addition, its electronic amplifying mechanism is totally different and definitely more advantageous as regards efficiency.

United States Patent 2,511,407 to W. Kleen et al. relates to another type of tube comprising two coaxial circular electrodes between which is applied a constant, radial electric field and a magnetic field parallel to the common axis of the electrodes, across the space between these electrodes, which space, however, is not equipotential. A beam fed into this space describes a circular trajectory under the action of two transverse forces, one of which is the electric force due to the radial electric field, the other being the Lorentz force due to the magnetic field and the velocity of the electrons. An ultra-high-frequency wave traveling along the delay line constituted by one of the circular electrodes interacts with the beam, being amplified if the respective phase and beam velocities are equal.

The tube according to the invention differs from this type of tube in that the space in which the beam propagates is free of any electric field, and that the beam velocity, expressed in volts, is equal to the potential of the structure limiting that space. The beam describes a circular trajectory under the action of two transverse forces, one of which is the Lorentz force as in the former tube, the other, however, being the centrifugal force. Thus, the electrons are subjected to the same forces as in a cyclotron, although the exchange of energy takes place in the opposite direction. For this reason, this tube may be termed an "anti-cyclotron." It has the advantage that, assuming similar performances, it can be built with a magnetic field much weaker and potentials lower than in the previous tube, which facilitates the arrangement of supplying sources. Recalling that it has been calculated hereinbefore that, under a set of predetermined conditions, the tube according to the application operates under $V=625$ v. and $B=28$ gauss, it should be indicated by way of comparison that, for a tube according to United States Patent 2,511,407, assuming the same values of v and r , it is necessary to supply, respectively, 2,500 v. and 550 gauss.

Figures 10 and 11 show, inside a vacuum-tight cylindrical envelope 106, a delay line 101, for instance, a helix, circularly wound around the axis of the tube. A decoupling screen 111, fixed to the envelope 106, protrudes radially into the tube, for mutually decoupling the two extremities of delay line 101. An electron gun comprising a Wehnelt electrode 116, an emissive cathode 115, and an accelerating anode 114, is arranged to inject a ribbon shaped electron beam 123 through the helix 101, nearer the outer periphery thereof than the inner one. An output connection 107 is coupled to the delay line extremity adjacent to the gun. At opposed extremity of the helix, several turns 129 are coated with a substance that fully absorbs the ultra-high-frequency wave.

Power is supplied to the tube by a direct current source 119 having its positive pole connected to the envelope 106 and also to the line 101, the accelerating anode 114 being, on the other hand, connected to this line. The cathode 115 is connected through the connection 117 to a negative potential with respect to the anode 114, and the Wehnelt electrode 116 is connected through the connection 118 to a still more negative bias potential. In this manner, the space within the turns of the helix 101 is equipotential, i.e., it is free of any direct current electric field, while the electrons emitted from the cathode 115 enter this space with a velocity expressed in volts precisely equal to the potential with respect to the cathode imparted to this space. By adjusting the potential of the cathode, this velocity is adjusted to a desired value.

As shown in Figure 11, the tube is located between two polar pieces N, S, providing an axial, uniform, time-constant magnetic field traversing the space within the

tube perpendicular to the plane of delay line and of electron beam. The sense of the magnetic field is such that electrons entering the helix 101 have their trajectories curved circularly clockwise, and the strength of this field is such that the circular trajectories are coaxial with the delay line. After leaving the helix at 129, electrons are collected by the decoupling screen 111 operating as collector. Magnetic poles N and S are excited by coils 127 and 128 supplied by a direct current source 126 through a resistor 125, and the exciting current is adjustable by acting upon the resistor 125, the adjustment being ganged with the emissive cathode potential adjustment by means of a symbolically indicated dotted mechanical connection 124.

Operation.—The tube of Figures 10 and 11 operates as follows:

Let B again be the induction of the magnetic field prevailing in the tube and V the potential difference between the helix and cathode. The electron beam 123, accelerated by the potential V of the anode 114, enters the helix with a velocity

$$v_{\text{cm./sec.}} = 6.10^7 \sqrt{V} \text{ volts} \quad (4)$$

Conventionally, this velocity v shall hereinafter be expressed by the potential V (volts).

In accordance with Larmor's law, this beam again describes a circle in the space free of electric field inside the helix, with an angular velocity:

$$\omega = \frac{e}{m} B \quad (5)$$

where e and m are, respectively the charge and the mass of an electron.

If the beam is again to describe a circular trajectory centered on the tube axis and of a given radius r , the angular velocity

$$\frac{v}{r}$$

must be equal to ω , and hence V and B must be connected by the equation:

$$\frac{6.10^7 \sqrt{V}}{r} = \frac{e}{m} B \quad (6)$$

Now, if the delay line has propagation characteristics such that a predetermined spatial harmonic propagates with a phase velocity corresponding to a given phase angular velocity in the direction of the beam while its group velocity is directed in the opposite direction, i.e., if this harmonic is a backward wave, and if the induction B is so selected that ω is equal to this phase angular velocity, then there will arise an interaction between the electron beam and the backward wave according to the well-known backward interaction process and the tube will operate as backward wave oscillator. It is known that a helix displays such a characteristic for some frequency bands and phase propagation velocities. The backward wave energy, propagating within the helix towards the output 107, is collected on the output, while any forward propagating wave component is absorbed by the attenuation 129, as is well known in backward wave oscillator art.

Applicants have established that, if the electron beam is to yield energy to the ultra-high-frequency electromagnetic field, it is necessary that the beam circle radius r is greater than the radius of the circle along which extends the longitudinal axis of the helix. This is why the gun 114, 115 and 116 has been placed so that the beam 123 passes nearer the outer periphery of the helix 101 than the inner one.

The tube oscillates at such a frequency that the phase angular velocity, which, as is well known, depends on frequency, is equal to the beam angular velocity, as defined by Formula 5. Since this angular velocity is determined by the magnetic field B, a frequency variation will be obtained by varying the magnetic field by means

of resistor 125. If the beam, nevertheless, is to continue describing, in a broad frequency band, a concentric circular trajectory of constant radius r , it is necessary to accompany this magnetic field variation with a variation of the accelerating potential V , by means of potential supply variation of the connection 117, so as to satisfy the law expressed by Formula 6. For this purpose, the adjustments of B and V are preferably ganged, as indicated by the symbolical mechanical connection 124.

The backward wave oscillator according to the present invention differs from the well-known O-type backward wave oscillator in that while the space in which the beam propagates is in both cases free of electric field, the beam describes a circular trajectory in the tube according to the present invention, in contradistinction with the linear trajectory of the O-type backward wave oscillator. Therefore, for a given performance, the oscillator according to the present invention occupies less space. Moreover, with respect to well-known circular M-type backward type oscillator, the present invention differs in that the beam moves under the action of a transverse Lorentz force and of an opposite centrifugal force, in a space free of electric field, in contradistinction to two crossed electric and magnetic fields of an M-type oscillator, in which the beam moves under the action of a transverse Lorentz force and of an opposite electric force. Assuming similar size and performance, the oscillator according to the present invention can be built with a magnetic field much weaker and potentials lower than in the previous tube, which facilitates the arrangement of the supply sources. For instance, assuming the velocity v of the electrons to be 15,000 km./sec. and the radius $r=3$ cm., it may be calculated from Formulae 4, 5 and 6 that $B=28$ gauss and $V=625$ volts. A calculation shows that for a circular M-type backward wave oscillator, assuming the same values of v , r and generated frequency, it is necessary to supply, respectively, 550 gauss and 2500 volts.

While the backward wave oscillator has been specifically described herein only with reference to Figures 10 and 11, it is understood that the other embodiments described in connection with Figures 1 through 9 may also be operated as such by adapting the same in a corresponding manner, i.e., provide therefor the attenuating or absorbing means in connection with the end of the delay line opposite the electron gun, by removing any output coupling at this end unless it is connected with an external attenuation or absorbing means, and by suitably adjusting the parameters to provide the desired operational effect.

We claim:

1. An electron discharge tube comprising, in an evacuated envelope, a curved conductive structure defining a circular electron and wave interaction duct having an output and delay elements for ultra-high-frequency wave energy propagating in said duct, a terminal connection to said structure for applying a potential to determine an equipotential throughout said duct, an electron gun positioned at one end of said duct adjacent said output to emit a beam of electrons into said duct in a plane perpendicular to the axis of curvature of said structure at a velocity having a resultant directed perpendicularly to said axis and a value expressed in volts substantially equal to said potential, means for establishing in said duct a uniform magnetic field having its lines of force directed parallel to said axis, the delaying characteristics of said delay elements and the magnitude of said induction being such as to cause the angular velocity of phase propagation, in the same sense as said beam of electrons, of ultra-high-frequency wave energy propagating in said duct in the opposite direction to said beam of electrons to be substantially equal to the angular velocity of said electrons, means associated with said structure at a point thereof remote from said electron gun for attenuating

ultra-high-frequency wave energy, and means for collecting wave energy at said output.

2. A microwave oscillator comprising first means including an electron source and a collector electrode defining therebetween a path of electron flow, a wave guiding structure positioned along said path in which there is induced by the electron flow an electromagnetic wave which travels in a direction opposite that of electron flow, means coupled to the said wave guiding structure for abstracting the induced wave, potential supplying means for imparting to the space of the electron flow in said path an equipotential equal to said flow velocity expressed in potential units, and means for curving the electron flow in said path in a predetermined plane comprising means for establishing an essentially uniform magnetic field having its lines of force directed perpendicular to said plane and acting on said flow.

3. An oscillator as claimed in claim 2, further comprising means for changing the frequency of the induced wave comprising means for varying the strength of said magnetic field.

4. An oscillator as claimed in claim 3, further comprising accelerating means for varying said electron flow velocity.

5. An oscillator as claimed in claim 2, wherein the axis of said guiding structure is circularly curved along a circle of predetermined radius, and wherein said electron source is so positioned that the radius of said electron flow circular path is greater than said longitudinal axis circle radius.

6. An ultra-high-frequency oscillator tube adapted to produce oscillations of a frequency which is adjustable at will over a relatively wide, uninterrupted band, said tube comprising a circularly curved delay line having a geometrically periodical structure, an electron emissive source adjacent one end of said line and positioned to emit a beam of electrons in coupled relationship with said line thereby to induce electromagnetic wave energy in said line to interact with a space harmonic thereof, said line having its two ends mutually uncoupled, means disposed at least at the other end of said line for absorbing ultra-high-frequency energy propagated along said line in the same direction as the beam thereby substantially to prevent reflections from said other end and thus to render said line electrically aperiodic within the limit of said band, means for directing said beam of electrons along a path substantially parallel to said line and at a velocity substantially equal to the apparent or phase velocity of a negative space harmonic of electromagnetic wave energy propagating in said line in the opposite direction to the beam, thereby to cause interaction between said beam and said negative space harmonic for sustained flow of energy toward said electron emissive source, means adjacent said source for transferring said energy to an external load circuit, potential supplying means for imparting to the space between said beam and said line an equipotential equal to said beam velocity expressed in potential units, and means for circularly curving the path of said electron beam to be substantially coaxial with said delay line including means for establishing an essentially uniform magnetic field having its lines of force directed perpendicular to said curvature plane and acting on said beam.

7. An ultra-high-frequency oscillator tube adapted to produce oscillations of a frequency which is adjustable at will over a relatively wide band, said tube comprising a wave-guiding structure having effectively a first end and a second end, cathode means for emitting electrons adapted to propagate from said first end toward said second end along said wave-guiding structure in coupled relationship therewith to thereby induce electromagnetic wave energy in said wave-guiding structure and to interact with a space harmonic thereof, means for directing said electrons to propagate along said wave-guiding structure in coupled relationship therewith in a direction from

said first end toward said second end of said wave-guiding structure and at a velocity substantially equal to the apparent or phase velocity of a negative space harmonic of the electromagnetic wave energy propagating in said wave-guiding structure in the opposite direction to the flow of said electrons, thereby to cause interaction between said electrons and said negative space harmonic for sustained flow of energy toward said cathode means, means near said first end of said wave-guiding structure and operatively connected thereto for transferring said energy to an external load circuit, means for producing in the space of propagation of said electrons an equipotential equal to the flow velocity thereof expressed in potential units, and means for curving the electron flow in a predetermined plane including means for establishing an essentially uniform magnetic field having its lines of force directed perpendicularly to said plane and acting on said electron flow.

8. An ultra-high-frequency oscillator tube according to claim 7, further comprising means at least near one end of said wave-guiding structure to minimize reflections thereat of said induced electromagnetic wave.

9. A traveling wave, ultra-high-frequency electron discharge device adapted to produce oscillations of a frequency which is adjustable at will over a relatively wide band, said tube comprising a wave-guiding structure having effectively a first end and a second end, cathode means in said system for emitting electrons adapted to propagate from said first end toward said second end along said wave-guiding structure and to interact with a space harmonic thereof, means for directing said electrons to propagate along said wave-guiding structure in coupled relationship therewith in a direction from said first end toward said second end to said wave-guiding structure and at a velocity substantially equal to the apparent or phase velocity of a negative space harmonic of the electromagnetic wave energy propagating in said wave-guiding struc-

ture in the opposite direction to the flow of said electrons, thereby to cause interaction between said electrons and said negative space harmonic for sustained flow of energy toward said cathode means including means for producing in the space of propagation of the electrons an equipotential equal to the flow velocity of the electrons expressed in potential units, and means producing an essentially uniform magnetic field having its lines of force directed perpendicularly to a predetermined plane and acting on electron flow to curve the same in said plane, and means near said first end of said wave-guiding structure and operatively connected thereto for transferring said energy to an external load circuit.

10. A microwave oscillator comprising first means including an electron source and a collector electrode defining therebetween a path of electron flow, a wave-guiding structure positioned along said path in which there is induced by the electron flow an electromagnetic wave which travels in a direction opposite that of electron flow, means coupled to said wave-guiding structure for abstracting the induced wave, means for producing in the space of electron flow an equipotential equal to the flow velocity of electrons expressed in potential units, and means for curving the electron flow in said path in a predetermined plane including means for establishing an essentially uniform magnetic field having its lines of force directed perpendicularly to said plane and acting on said electron flow.

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