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3,158,779

TRAVELING-WAVE ELECTRONIC MICROWAVE INTERACTION GUIDE DEVICES

Filed Sept. 29, 1960

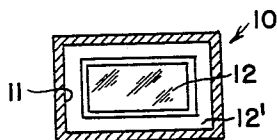
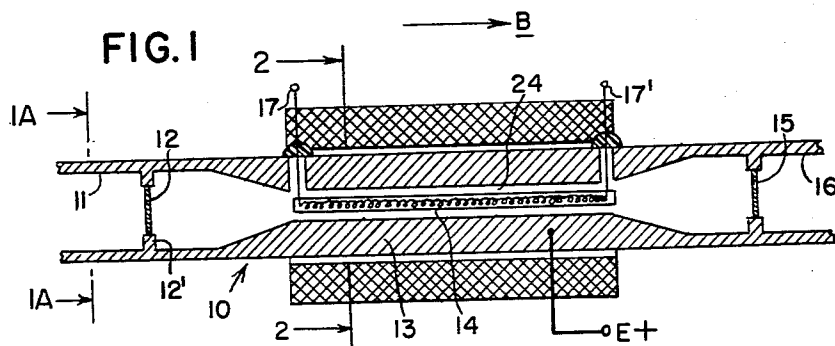


FIG. 1A

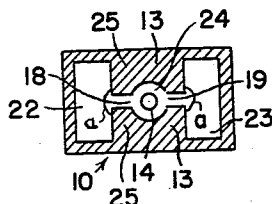


FIG. 2

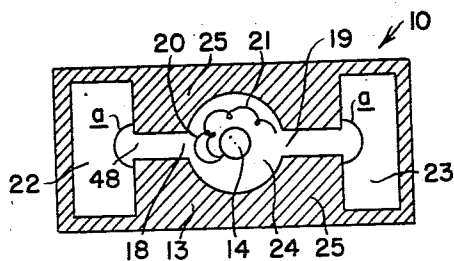


FIG. 3

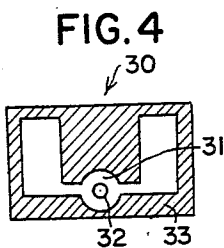


FIG. 4

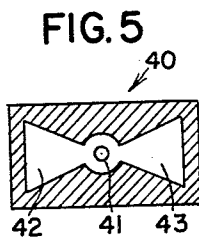


FIG. 5

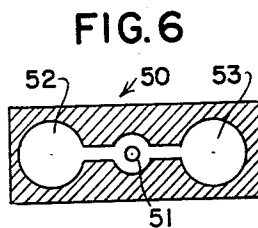


FIG. 6

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TRAVELING-WAVE ELECTRONIC MICROWAVE
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This invention relates to electronic microwave signal amplifiers and/or oscillator microwave guide devices, and more particularly to electromagnetic waveguide devices wherein interaction takes place between the electron stream and an electromagnetic wave propagated in the wave guide, of the type described in "Proceedings of the Symposium on Electronic Wave Guides," published in Micro Wave Research Institute Proceedings, Volume 8 of 1958. The wave guide devices of the present invention embody all operating elements of such known wave-guide devices as described in the aforesaid "Proceedings of the Symposium on Electronic Wave Guides" except for the modifications of the present invention as hereinafter described.

Travelling wave tubes, velocity modulation tubes, magnetrons, and the like, have been heretofore applied as amplifying or oscillating devices for microwave signals. The construction of such devices has been attended with considerable difficulty due to the fact that a slow wave circuit or cavity resonator becomes smaller in proportion to the wave length, where the frequency of the signal becomes exceedingly high, for instance, above 50,000 mc.

An important object of the present invention is to eliminate such difficulties. In microwave devices according to the present invention, instead of employing a slow wave circuit or a cavity resonator, useful interaction is effected between electromagnetic wave propagation in a wave guide and an electron stream therein. The resulting structure is simplified, since there is no slow wave circuit, and it becomes easy to produce. Several embodiments and the operating principles of the present invention are set forth hereinafter, reference being had to the accompanying drawing, wherein:

FIGS. 1, 1-A and 2 show, respectively, the vertical section longitudinally of a microwave device of the present invention, and transverse cross-sectional views taken along the lines 1-A—1-A and 2—2 of FIG. 1;

FIG. 3 illustrates diagrammatically the movement of electrons in the device of FIG. 1; and

FIGS. 4, 5 and 6 show transverse cross-sectional views of other embodiments of the invention.

FIGS. 1, 1-A and 2 illustrate one form of the microwave device 10 of the present invention. The microwave signals are impressed into a wave guide at input side 11. An airtight window 12, of glass for instance, is mounted transversely of the wave guide input 11 in frame 12' therein and sealed in. Window 12 passes the waves along. A ridge wave guide 13 of typical cross-section, as shown in FIG. 2, acts as an anode. The central region is a longitudinal, cylindrical passage for microwave signals, as in the TEM mode. A cathode 14 is positioned axially along the center passage of the anode guide 13. A corresponding window 15 and wave guide terminal 16 are at the output side of device 10. Ridge wave guide 13 is maintained at a high potential $E+$ with respect to the cathode 14 which emits electrons. The longitudinal cathode is preferably a coaxial cylinder, oxide-coated to emit electrons about a coiled heater element with terminals 17, 17'.

The device is evacuated like a tube, and is operated in the presence of a magnetic field along the axial direc-

tion, indicated by B said field being produced by coil C. The electromagnetic signal energy entering from the input wave guide 11 performs an interaction with the cathode-emitted electrons along the ridge wave guide 13 as it propagates therethrough and goes out from the output wave guide 16 after being amplified. The direction of propagation of the electromagnetic signal wave is symmetrical, and can enter from either end of the wave guide and go out through the other wave guide end.

FIG. 2 shows a section taken along line 2—2 of FIG. 1. The cathode 14 is positioned in the center of the ridge wave guide 13. When the ridge wave guide 13 is maintained at a suitably high potential with respect to the cathode 14, and when a magnetic field B is applied along the axial direction, the electrons emitted from the cathode 14 revolve around the cathode 14 in a known cycloidal movement. A transverse microwave signal, as a TEM, propagating along the ridge wave guide 13, produces an electric field a, a , as shown by the lines across ridge gaps 18, 19. When the electrons revolved about the cathode 14 in a cycloidal movement, arrive at gap 18, they are accelerated. When the high-frequency electric field a, a in the gap 18 is of a phase suitable for accelerating the electrons, they will absorb energy from the electric field a, a , and thereupon be attracted to the cathode 14, returning to it again, and not continuing the revolving cycloidal movement.

FIG. 3 illustrates the movement of emitted electrons from cathode 14. The path 20 of the electrons is for those which have been accelerated by the high-frequency electric field a, a at the gap 18. On the other hand, those electrons which have been slowed or reduced in speed by the high-frequency field a, a , at the gap 18, continue their cycloidal revolution without being returned to cathode 14. The reason for the latter mode is that such electrons had imparted part of their energy to the electric field a, a . The path 21 shown, is for electrons that have thus been slowed at the gap 18 by the high-frequency electric field a, a , a cycloidal movement. The impressed electromagnetic wave propagating longitudinally along the ridge wave guide 13 is not slowed down, its phase velocity actually becoming larger than that of the speed of light c . Therefore, the phase of the electric field propagating along guide 13 by the interaction with the aforesaid electrons at gap 18, will advance more than several wave lengths during the interval that such electrons (which have gone through a speed reduction by the high-frequency electric field a, a at gap 18) will reach the opposite gap 19 through their cycloidal movement.

It is practical to adjust the magnitudes of the accelerating voltage $E+$ for the electrons, the axial magnitude field B, and so forth, so that an optimum interaction of electrons and propagation of axial waves will occur, at such phase relation capable of speed-reducing the electrons (in cycloidal movement from the gap 18 to gap 19) through the high-frequency electric field that is traveling longitudinally more than several wave lengths behind the phase of the high-frequency electric field a, a that so acts upon such electrons. When the synchronized condition of the applied electromagnetic signal field and the electron stream is satisfied, the emitted electrons will continue to revolve cycloidally, imparting energy to the electromagnetic field every time the electrons arrive at gaps 18 and 19, finally arriving at the anode, namely the ridge wave guide 13. In this manner, the applied signal high-frequency electromagnetic wave in the circuit is amplified. If a portion of the amplified output signal, as at 16, is reflected or fed back to the input guide 11, the microwave device 10 will act as an oscillator.

A theoretical explanation of the synchronized condition between the electrons and the high-frequency electromag-

netic field, follows. Reference is made to a related system of the co-pending patent application Serial No. 832,588 filed August 10, 1959, for "Microwave Device," by M. Miya, assigned to the assignee of the present application. Assuming the angular frequency of the electromagnetic wave as ω , and the revolving angular velocity of electrons as ω_e , then the necessary time T_e for the electrons to travel from the gap 18 to gap 19, that is, the time for making a 180° revolution around the cathode 14, is expressed as follows:

$$T_e = \frac{\pi}{\omega_e} \quad (1)$$

Time, T_n , which is the period from the time when the electric field at the gap is of a phase that reduces the electron speed to the time when the electric field at the gap 19 is also of a phase that reduces the electron speed, is given by the following equation:

$$T_n = \frac{2\pi}{\omega} \left(\frac{1}{2} + n \right) \quad (2)$$

where $n=0, 1, 2 \dots$

The necessary condition that the electrons be in synchronism with the electromagnetic field, and impart energy to the electromagnetic field, is $T_e = T_n$. Therefore, from Equations 1 and 2, the following Equation 3 is obtained:

$$\omega_e = \frac{\omega}{2n+1} \quad (3)$$

This Equation 3 represents the synchronized condition. As is now clear from Equation 3, it is feasible to use a value of n that is relatively large, even when the frequency used is high and is large. Therefore, the resultant angular velocity of electrons ω_e need not be correspondingly large. The angular velocity ω_e is given approximately by the following equation:

$$\omega_e = \frac{\epsilon B}{2} \left[1 - \sqrt{\frac{8}{\epsilon B^2} \cdot \frac{V}{(R^2 - r^2)}} \right] \quad (4)$$

where V is the accelerating voltage, R and r are the radii of the anode and cathode, respectively, and ϵ is the specific charge of the electrons. Using Equation 4, the synchronized condition of Equation 3 can be expressed in terms of the frequency, voltage and magnetic fields, as follows:

$$V = \frac{2\pi(R^2 - r^2)f}{2(2n+1)} \left[B - \frac{f}{(2n+1)\epsilon} \right] \quad (5)$$

where f represents the frequency. From the above equation, it will be understood that V and B can be set at practical values only by selecting n to be large, even if f becomes exceedingly large, say 50 kmc. and above.

The present invention is not to be understood as limited to the aforesaid embodiment 10. Thus, the cross-sectional configuration of device 10 as shown in FIG. 2, may be modified as shown in FIGS. 4, 5 and 6.

The ridge wave guide 13 of FIGS. 1 and 2 contains two symmetrical, oblong-shaped, longitudinal end regions 22, 23 of a non-resonant nature. The end regions 22, 23 communicate with the transverse gap across a, a , and the central longitudinal cylindrical region 24, also of non-resonant dimension. The resultant opposed symmetrical, solid, longitudinal channels 25, 25 co-act with the longitudinal regions 23, 22, 24, 25, and the gaps 18, 19, to comprise the ridge wave guide 13. Non-resonant dimensioning thereof results in rather broad-band operation, as an amplifier of the device 10. For application as an oscillator, resonant dimensions could be indicated.

The ridge wave guide corresponding to 13 in device 10 may assume configurations as illustrated in FIGS. 4, 5 and 6, among others. In FIG. 4, the device 30, otherwise similar in combination and operation to device 10, has the cylindrical, longitudinal region 31, off-center of device 30. The cathode 32, however, is central therein. The lower wall 33 of the wave guide contains the correspond-

ing cylindrical bore for the axial path. Device 40 has a central cathode 41 arrangement, with the side regions 42, 43 of triangular cross-section. Device 50 has a central cathode 51 arrangement, with cylindrical, longitudinal side regions 52, 53.

The microwave device of the present invention is relatively inexpensive to fabricate, even for exceedingly high-frequency use. It employs no cavity resonator or slow wave circuit sections. Practical, relatively low values of anode voltage and external magnetic field are feasible even for high-frequency operation. Broad-band operation is attained therewith.

It will be apparent to those skilled in the art that the novel principles of the invention disclosed herein in connection with specific exemplifications thereof, will suggest various other modifications and applications of the same. It is accordingly desired that in construing the breadth of the appended claims, they shall not be limited to the specific exemplifications of the invention described above.

I claim:

1. In an electronic microwave guide device, a ridge wave guide comprising a conductive envelope having an input and an output end; a longitudinal, substantially cylindrical space region and two spaced gap regions extending from and communicating with said space region, and a longitudinal cathode mounted within said longitudinal space region along the longitudinal axis of said cylindrical space region, whereby electrons emitted by said cathode interact with microwave signals propagated along said ridge wave guide to impart amplification energy to the signals; said cylindrical space region and said gap regions communicating with said input and output ends; said cylindrical space region being continuous and substantially straight between said input and output ends; the width of said gap regions adjacent said cylindrical space region being substantially less than the diameter of said cylindrical space region; the length of said gap regions being equal to the length of said cylindrical space region.

2. In an electronic microwave guide device, an input guide element, an output guide element, a ridge wave guide coupled between said input and output guide elements and comprising a conductive envelope having an input and an output end; and containing a longitudinal, substantially cylindrical space region and two spaced gap regions extending from and communicating with said space region, and a longitudinal cathode mounted concentrically within said cylindrical space region astride said gap regions, whereby electrons emitted by said cathode in the presence of a unidirectional axial magnetic field interact with microwave signals propagated along said ridge wave guide, with said guide elements maintained at an anode potential to impart amplification energy to the signals emergent at said output guide element; said cylindrical space region and said gap regions communicating with said input and output ends; said cylindrical space region being continuous and substantially straight between said input and output ends; the width of said gap regions adjacent said cylindrical space region being substantially less than the diameter of said cylindrical space region; the length of said gap regions being equal to the length of said cylindrical space region; said gap regions being substantially wider than the diameter of said cylindrical space region at the gap regions remote from said cylindrical space region.

3. In an electronic microwave guide device, an input wave guide and an output wave guide for microwave signals, a ridge wave guide integrally coupled between said input and output wave guides comprising a conductive envelope having an input and an output end; and including two spaced longitudinal guide elements containing a longitudinal, substantially cylindrical space region therebetween and two spaced gap regions extending from and communicating with said cylindrical space region, and a longitudinal cathode mounted concentrically within said

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cylindrical space region astride said gap regions, whereby electrons emitted by said cathode in the presence of a unidirectional axial magnetic field interact with the microwave signals propagated along said ridge wave guide, with said guide elements maintained at an anode potential to impart amplification energy to the signals emergent at said output wave guide; said cylindrical space region and said gap regions communicating with said input and output ends; said cylindrical space region being continuous and substantially straight between said input and output ends; the width of said gap regions adjacent said cylindrical space region being substantially less than the diameter of said cylindrical space region; the length of said gap regions being equal to the length of said cylindrical space region; said gap regions being substantially wider than the diameter of said cylindrical space region at the gap regions remote from said cylindrical space region.

4. In an electronic microwave guide device as claimed in claim 1, a window sealed-in across each end of the cylindrical space region for maintaining it in an evacuated condition within the device.

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5. In an electronic microwave guide device as claimed in claim 3, a window sealed-in across both said input and output wave guides for maintaining an evacuated condition within said ridge wave guide.

6. In an electronic microwave guide device as claimed in claim 1, one of said longitudinal guide elements being integral with an outer wall of said ridge wave guide.

7. In an electronic microwave guide device as claimed in claim 2, one of said longitudinal elements being integral with an outer wall of said ridge wave guide.

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