March 16, 1954 J. W. TILEY 2,672,572

TRAVELING WAVE TUBE

Filed Nov. 28, 1947 3 Sheets-Sheet 1

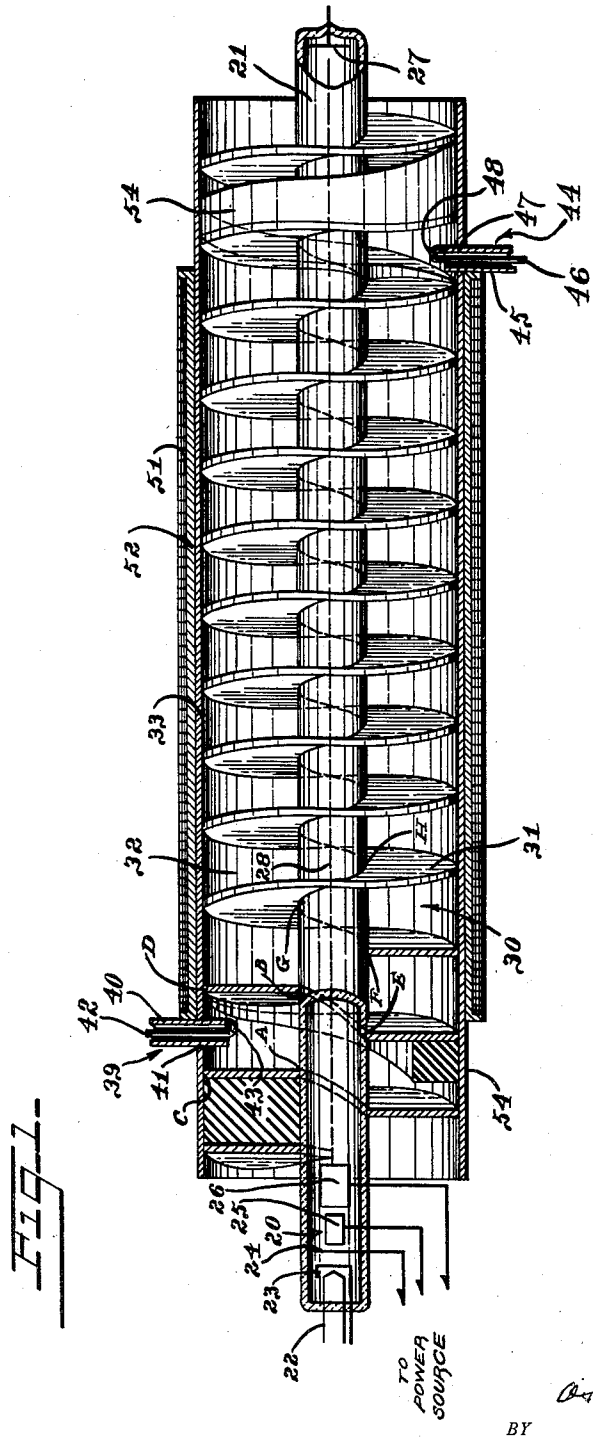



FIG. 1.

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TRAVELING WAVE TUBE

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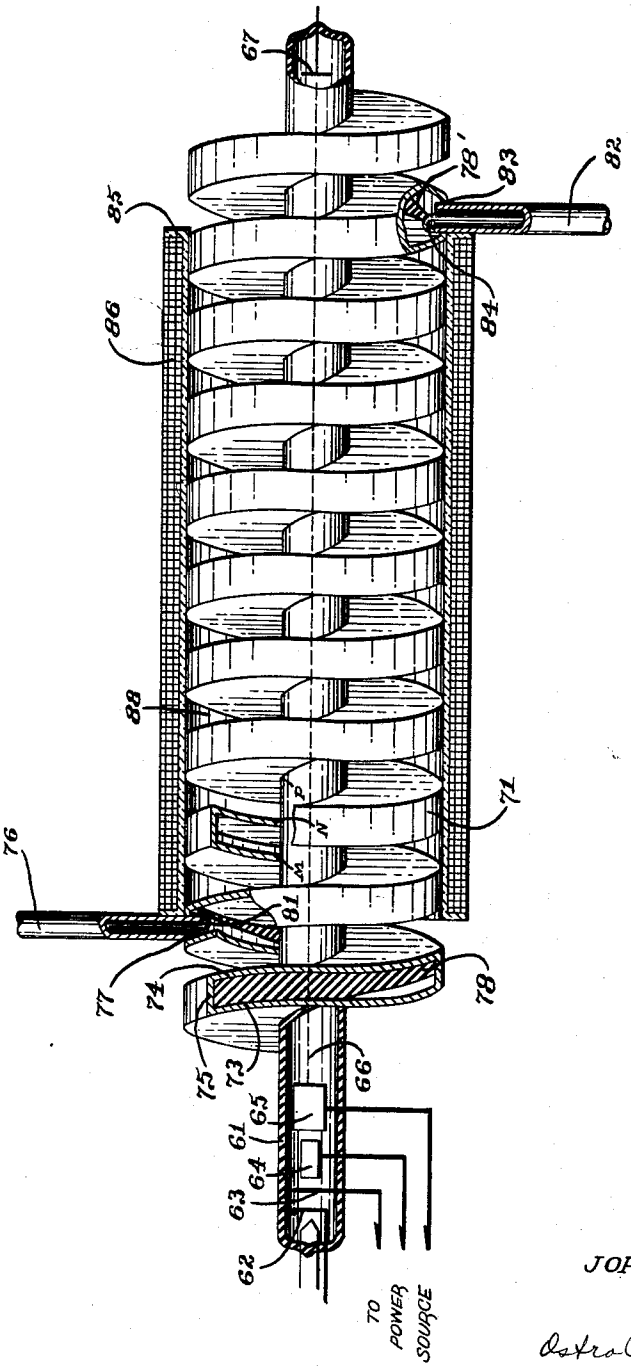



FIG-2

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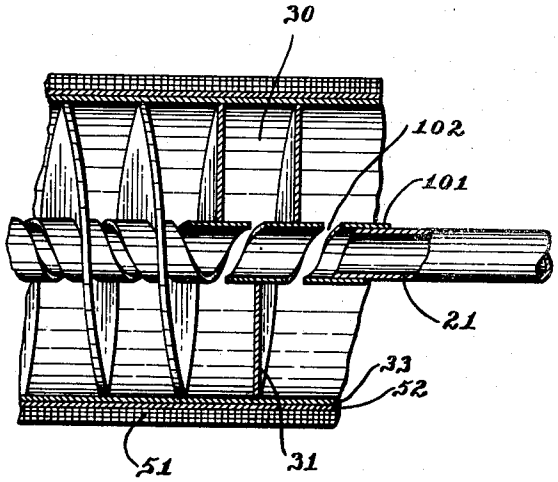
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March 16, 1954 J. W. TILEY 2,672,572

TRAVELING WAVE TUBE

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Fig. 3.



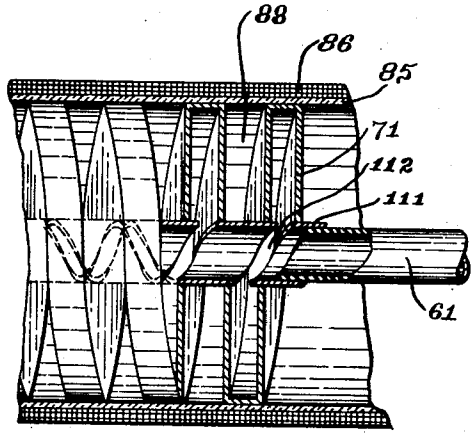




Fig. 4.

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# UNITED STATES PATENT OFFICE

2,672,572

## TRAVELING WAVE TUBE

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Application November 28, 1947, Serial No. 788,724

9 Claims. (Cl. 315—3)

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This invention relates in general to the electron tube art, and more particularly to a novel electromagnetic traveling wave tube having special application in high frequency and broad band electrical systems. This application is a continuation-in-part of my co-pending application Serial No. 761,798 filed July 18, 1947, now Patent No. 2,541,843.

In electrical systems such as television, pulse-position modulation and radar, it has often been extremely difficult to obtain adequate and uniform amplification over the frequency spectrum encompassed by the signal. Ordinary triodes, even when incorporated in special circuits, fail to provide a usable gain in such applications. Recent designs, such as the lighthouse tube, and the velocity modulation tube as exemplified by the klystron, can provide reasonable gain solely in narrow band width operation. An attempt to use a klystron or like tube in the microwave region with a band width of fifty megacycles or greater will result generally in a gain of less than unity.

A recent electronic development, known as the beam traveling wave tube, overcomes the limitations of the more conventional tube types, and has been successfully tested as an efficient amplifier of signals having a mean frequency of the order of thousands of megacycles with an over-all band width of the order of eight hundred megacycles. Theoretically, even much wider bands may be amplified by the device without sacrifice of gain.

For a description and illustration of this development, reference is made to the publication "Bell Laboratories Record" of December, 1946, and to the article therein entitled "The Beam Traveling Wave Tube" by J. R. Pierce. In this reference the traveling wave tube is described as constituted of an electron gun similar to those employed in cathode ray tubes. An electron beam generated by the gun is directed in a narrow beam along the axis of a long evacuated tube and impinged upon a collector anode. Within the tube, and surrounding the beam axis, is a closely wound wire helix which is excited at the electron gun end thereof by the weak signal to be amplified and which provides at the collector end thereof the amplified output signal. The tube contains no signal grids in the conventional sense.

Broadly speaking, the applied signal travels along the wire helix as an electromagnetic wave at a speed approaching the speed of light. As is determined by the pitch of the helix, the wave

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travels axially of the tube at a fraction of the speed of light; and the electron gun and collector anode potentials are arranged so that the average axial velocity of the electron beam through the helix is somewhat greater than the axial wave velocity.

Interaction of the electron beam and electromagnetic field components extending from the helix produces the signal amplification. The greater the electron current and the longer the helix, the greater is the gain. In transit through the helix, the average electron velocity is reduced, and the energy drop represented by this decreased velocity is imparted to the signal. The tube does not require a tuned circuit in the signal path, the wire helix being in effect an all pass transmission line. Hence the tube is capable of operation over an exceedingly wide frequency range. In practice this range is limited somewhat by the impedance match of the helix to the external circuits.

In operation the signal appearing on the helix acts on the electron stream and gradually produces fluctuations in velocity and density. The density modulated electron beam delivers energy to the wave and over the helix section nearest the collector there is a substantially uniform gain per unit length of travel.

Th present invention contemplates and has as a primary object the provision of electromagnetic traveling wave tubes of novel and improved design having wide application as broad band microwave amplifiers, oscillators, frequency convertors, or the like. As in the electron tubes disclosed in my above-identified patent application, the electromagnetic traveling wave tubes of the present invention differ from prior art traveling wave tubes in that wave guides are utilized for directing wave signals around the path of an electron beam. These wave guides permit direct coupling of the electromagnetic fields therein and the tube electron beam, and preclude excessive energy radiation and undesirable coupling with external fields.

In the aforementioned patent application it was demonstrated that signal amplification could be obtained in an electromagnetic traveling wave tube by causing an electron beam to traverse the axis of first and second or input and output helical wave guide sections of predetermined pitch and number of turns. The input wave guide was energized by the weak incoming signal, whereby the electron beam was bunched or density modulated. The modulated beam was then caused to traverse a second or output helical

wave guide section and to deliver energy thereto to provide the amplified output signal.

In a tube of this construction, input and output wave guides are spaced axially of the electron beam. When certain conditions of beam velocity and helix structure are properly satisfied, considerable gain is obtained and the electron tubes are capable of either amplifier or oscillator operation; the latter being accomplished by coupling a predetermined portion of the output signal in the correct phase to the input wave guide. In connection with traveling wave tubes utilizing independent input and output wave guide sections, it has been determined that the optimum average beam velocity through the guides is equal to the axial component of velocity of the electromagnetic traveling wave.

In accordance with the principles of the present invention a single helical wave guide is utilized for both modulating and extracting energy from an electron beam. The single wave guide employed is constructed essentially the same as the input wave guide of the systems disclosed in the above named patent application.

A particular advantage of the present construction to be described in detail below is that the single wave guide utilized for electron beam modulation and signal output comprises a conductive helix of uniform pitch. The incoming signal is coupled into the wave guide at the input or electron gun end of the helical wave guide and the output signal is derived from the opposite end thereof.

Successful operation as amplifier or oscillator is accomplished by the utilization of an electron beam velocity somewhat above the axial velocity of the traveling wave. In transit through the tube each group of electrons delivers energy to the traveling wave and as a consequence thereof, the output signal is at a level considerably higher than that introduced at the input end of the guide.

It is therefore an object of the present invention to provide a beam-traveling wave electron tube characterized by inherent stability and high gain, and which utilizes a single helical wave guide structure for directing the wave energy about the path of the electron beam.

A further object of the present invention is to provide a velocity modulation type electron tube utilizing a single helical wave guide of uniform pitch for raising the intensity level of an input electromagnetic signal.

A still further object of the present invention is to provide a traveling wave electron tube of comparatively simple mechanical design and rugged overall construction.

It has been observed that frequency variations of the signal being amplified tend to affect the strength of the electric fields established by the wave guide and coupling with the electron beam. The present invention further contemplates the provision of novel helical wave guide structures which materially increase the frequency range over which wave guide electromagnetic traveling wave tubes may operate. Generally speaking, this is accomplished by capacitively loading the wave guide structure to maintain the strength of electric fields more nearly constant over wide band frequency variations of the input electromagnetic energy.

It is thus another object of the present invention to provide a helical wave guide structure adaptable to many types of traveling wave tubes,



which structure permits broad band operation thereof.

Still another object of the present invention is to provide means for capacitively loading a wave guide having an open side wall while permitting the fields extending from the wave guide to couple with an electron beam.

These and other objects of the present invention will now become apparent from the following detailed specification when taken in connection with the accompanying drawings in which

Figure 1 is a general side view partially in section of a helical wave guide traveling wave electron tube.

Figure 2 is a general side view partially in section of another embodiment of a traveling wave tube of the general type illustrated in Figure 1.

Figure 3 is a fragmentary side view partially in section of a helical wave guide tube structure illustrating a novel means of obtaining broad band wave guide operation; and

Figure 4 is a general side view partially in section of a wave guide structure similar in features and characteristics to that illustrated in Figure 3.

With reference now to the drawings and more particularly to Figure 1, there is illustrated an electron tube incorporating the features of the present invention and comprising, generally, a centrally disposed sealed and evacuated glass or similar dielectric cylinder 21.

Sealed into the left end of the glass cylinder 21 as viewed in Figure 1 are the electrodes of an electron gun 20, similar to those utilized in conventional cathode ray tube structures. As shown the electron gun 20 comprises a heater 22 and its associated cathode 23, a centrally perforated control grid 24 and focusing and accelerating hollow cylindrical electrodes 25 and 26, respectively. When the electrodes comprising the electron gun 20 are energized from a suitable power source (not shown) an axial beam of electrons of predetermined high velocity is generated and directed along the axis 28 of cylinder 21 toward a disc shaped collector electrode 27 sealed into the right-hand end of the tube as viewed in Figure 1.

Structural means required for supporting the electron gun electrodes have been omitted for clarity.

As electron beam tubes of the type included within the structure of the tube in Figure 1 are sufficiently well known in the electronic art, a further description thereof and of the energizing means therefor are considered unnecessary at this point.

In accordance with the broad principles of the present invention, the axial path of travel of the electron beam through tube 21 is substantially enclosed within a single helical wave guide structure 30, preferably of uniform pitch. As is clearly illustrated in Figure 1, the wave guide structure 30 is comprised of a thin highly conductive metallic strip 31 wound edgewise about and in contacting relationship with cylinder 21 at the aforementioned uniform pitch.

The outer edge of the conductive strip 31 defines a helix lying in electrical contacting relation with the inner cylindrical surface of an enclosing hollow metallic or otherwise conductive cylinder 33, coaxial with and extending substantially the length of tube 21. The helical strip 31 and enclosing metallic cylinder 33 thereby define a helical passage 32 of uniform rectangular cross-section which progresses axially of tube 21. In effect, therefore, helical passage 32 comprises a helical wave guide enclosed at any point by

two adjacent turns of strip 31, and by the metallic surface of the enclosing cylinder 33. The innermost wall of the helical passage 32 lies in the outer surface of dielectric cylinder 21, and is accordingly open insofar as radiation of electromagnetic fields is concerned.

Coupling means are provided for the interchange of electromagnetic wave energy with the helical wave guide passage 32. As illustrated, the outer cylindrical conductor 40 of a coaxial line 39 extends through a perforation 41 in metal cylinder 33 and enters helical passage 32. The end of inner conductor 42 of coaxial line 39 is curved as shown and electrically connected to the outer conductor 40 to form a small coupling loop 43. A similar coaxial line 44, comprising an outer conductor 45 and an inner conductor 46, extends through a perforation 47 in cylinder 33 and is terminated by coupling loop 48 within wave guide 32. It will be noted that coaxial lines 39 and 44 enter wave guide passage 32 at axially opposed ends thereof.

In order to maintain electrons traversing cylinder 21 within a sharply defined axial beam, means are provided for establishing a substantially uniform and unvarying axial magnetic field. As illustrated, this is accomplished by means of a multi-layer solenoid type coil 51 coaxial with tube 21 and wound upon an insulating cylindrical coil form 52 suitably secured over the metallic cylinder 33 between coaxial connectors 39 and 44. Coil 51 is preferably energized from a direct current source (not shown in the drawings).

In accordance with well understood principles, an electron which tends to travel a path divergent from the axis 28 of tube 21, and hence angularly of the field established by coil 51, will be urged back to axis 28 as a consequence of its interaction with the axial magnetic field.

For successful operation of the electron tube structure of Figure 1, it is desirable to preclude possible interference from stray electromagnetic fields and, further, to preclude internal wave reflections. Insofar as external electric fields are concerned, the conductive cylinder 33 and the helical strip 31 provide substantially complete shielding. A magnetic shield may be employed if found necessary.

To minimize internal signal reflections, helical wave guide structure 30 has been suitably electrically terminated and matched at the ends thereof. Thus, in the embodiment of Figure 1, impedance matching is effected at ends of the wave guide by means of two uniformly tapered, molded helical blocks 54. Blocks 54 are preferably constituted of a ceramic containing powdered graphite as the dissipating element; however, various other absorptive substances may be employed. By thus tapering the lossy material, a proper impedance match is readily obtained. This corresponds in effect with the utilization of tapered or wedge-shaped dissipative blocks as reflectionless terminations for conventional rectangular and other wave guides.

To insure reflectionless termination, each of the blocks 54 illustrated in Figure 1 is preferably made equal to at least one wave length at the lowest frequency of operation, as measured along the helix. Suitable termination may also be effected by uniformly tapering the spacing of the end turns of wave guide structure 30 to zero, and covering the tapering sections thereof with a power absorbing, semi-conductive substance.

The operation of the traveling wave electron tube illustrated in Figure 1 will now be described when effective as a signal amplifier. The incoming weak signal to be amplified is applied to the tube through coaxial line 39 and the amplified output is extracted through coaxial line 44. The input signal travels in a helical path through passage 32 at a velocity somewhat less than that of light. Standing waves are precluded by the impedance matching dissipative blocks 54.



In accordance with the general principles of traveling wave electron tube operation, the velocity component of electromagnetic wave energy within wave guide 32 parallel to the axis 28 of tube 21, is a fraction of the velocity of light, as determined by the pitch of the wave guide 32. As an example, if the length of the helical path through wave guide passage 32 is ten times as great as the axial distance encompassed thereby, then the velocity of wave propagation considered relative to the axis of tube 21 will be equal to one-tenth the velocity of light. It is therefore apparent that if an electron in the beam generated by the tube electron gun 20 has an average axial velocity equal to one-tenth the velocity of light, then the relative phase of the electromagnetic wave in helical passage 32 and this electron will remain unchanged.

If the electron velocities in the beam traversing the tube are of the order of one-tenth the velocity of light or less, then the following non-relativistic equation may be utilized as a guide for determining the electron velocity:

$$v=5.93\times10^{7}\sqrt{E} \text{ centimeters per second}$$

wherein:

E is equal to the voltage through which the beam electrons are accelerated.

The interaction of an electromagnetic wave traveling within helical wave guide 32 and an electron beam traversing the axis 28 of glass cylinder 21 is somewhat similar to the bunching action obtained in velocity modulation electron tubes. As will hereinbelow be demonstrated, the wave energy traveling within the wave guide 32 from the input coaxial line 39 to the output coaxial line 44 continuously density modulates the axial electron beam in accordance with the input signal variation so that the electron beam as it traverses the axis of tube 21 is progressively bunched to greater and greater bunch densities.

Simultaneously with the bunching effect of the electron beam, the beam delivers energy into wave guide 32 so that the wave energy therein progressively increases in intensity in its travel toward collector electrode 27.

The electromagnetic fields established by wave energy flowing within the helical wave guide passage 32 may best be visualized if the region between the inner surface of conductive cylinder 33 and the axis of tube 21 is considered as half a rectangular wave guide, the broad walls of which are the metallic surfaces of adjacent turns of helical strip 31. If the coupling loop 43, applying the input signal to be amplified to the helical wave guide 32, excites this wave guide in the $TE_{01}$ mode, then maximum electric field is produced between adjacent inner edges of the turns of helical strip 31. The electric field is normal to the strip 31 and diminishes sinusoidally to zero at the inner surface of metallic cylinder 33.

Points A, B, C and D may be considered as defining the cross-section of half a rectangular wave guide operating in the aforementioned mode.

As points C and D are metallically connected, there is no potential gradient therebetween. However, an electric field is established between points A and B by the exciting wave, which field cyclically varies in intensity as a function of time from a predetermined maximum in one direction through zero to a corresponding maximum in the opposite direction. The electric field between points A and B, of course, extends through the dielectric cylinder 21 and into the region of electron flow therethrough. In view of the fact that the input electromagnetic wave constantly progresses from left to right, as viewed in Figure 1, a given potential gradient may be considered as traveling around the inner edges of the helical strip 31 at a velocity approaching the velocity of light. Thus, if a voltage maximum in a particular direction appears between points A and B at one instant, it will appear at correspondingly later intervals of time between points E and F, B and G, F and H, and so on, until down the guide.

For purposes of illustration, let it be assumed that the dimensions of wave guide 32 are such that electromagnetic wave energy, introduced by coupling loop 43, travels around one complete turn of the helical passage 32 in a time period corresponding to one-half cycle of the input wave. Under such conditions there is a sinusoidal voltage distribution between opposed inner edges of the helical strip 31. If, under these conditions, and at a particular instant of time, the voltage between points A and B is a maximum in one direction, then the potential difference between points E and F will be zero, and between points B and G a maximum in the opposite direction.

Within the glass cylinder 21, the electric fields extending between opposed points on adjacent turns of the helical strip 31 may be resolved into components, one of which is parallel to the axis 28 of electron flow. The sense of these parallel field components is dependent upon the instantaneous polarity of the originating points. As wave energy passes from left to right through the helical wave guide passage 32, these field components may be considered as progressing axially from left to right, while simultaneously rotating about the tube axis. As previously mentioned, the axial velocity of propogation of the electromagnetic field components will be determined primarily by the pitch of the helical guide 32.

If the electron gun potentials were to be adjusted to provide an axial electron beam having a velocity substantially equal to the axial velocity of propagation of the input electromagnetic wave (as described in the aforementioned patent application and herein discussed for illustrative purposes only), a bunching action will take place as a result of the interaction of the traveling electron beam and the axially moving electric field components. In a given electron beam, individual electron velocities extend over a spectrum from a velocity considerably below to one considerably above the average velocity. If at the time electrons enter that portion of the axis 28 of tube 21 encompassed by the input helical wave guide 32, point B is positive with respect to point A; the entering electrons will experience an acceleration toward point B, whereby instantaneously the average velocity of electrons so influenced is increased.

Electrons whose initial velocity is equal to or somewhat less than the axial velocity of the traveling wave will be continuously accelerated as they progress along with the electric field component in its travel between points A and B, E and F, B and G, and the like. On the other hand, electrons which enter tube 21 in the region of helical guide structure 30 with a velocity greater than the axial velocity of the traveling wave, will be retarded somewhat and will continue to decrease in velocity in transit through the tube.

Electrons which enter the region of the helical wave guide 30 when point A is positive with respect to point B, will be retarded. Of these retarded electrons, the ones having the highest velocities may escape the retarding field and enter into a region of an accelerating field of the type previously described. The lowest velocity electrons may be sufficiently retarded to cause them to be overtaken by the following cycle of an accelerating field component.

Thus, as the electron beam traverses the section of tube 21 spanned by the helical wave guide structure 30, it is acted upon by the traveling wave field components so that electrons will become progressively bunched in the region of maximum positive potential points of the electric field. The degree of bunching, or density modulation, depends of course upon the intensity of the input electromagnetic wave and the effective length of the helical wave guide passage 32. The density modulated beam which is formed, as hereinabove described, finally impinges upon collector plate 27.

Since the electron beam is progressively reduced in velocity as it travels through the region of helical wave guide 32, it is preferable that the collector electrode 27 be connected to a source of potential (not shown) which is that required to produce such electron velocity, as determined by the above equation.

In order for the electron beam traveling wave tube illustrated in Figure 1 to amplify electromagnetic wave energy applied over coaxial connector 39, it is essential that there be a net transfer of energy from the electron beam to the electromagnetic wave traveling within the wave guide passage 32. From the foregoing discussion it is apparent that to accomplish this energy exchange it is necessary that the electron beam actually enter the region spanned by the wave guide structure 30 with an average electron velocity somewhat greater than the axial velocity of the electric field components which extend from the open wall of guide 32 into the region of the electron beam.

As in the above example, electrons entering a region of positive potential gradient will be accelerated in the direction of the collector electrode 27 while those entering a region of negative potential gradient will be retarded. However, since in operation the electrons enter the region of wave guide structure 30 with an average velocity greater than the axial velocity of the axial field components, electrons will remain in a region of retarding field for a longer period than in a region of accelerating field. At a given instant, therefore, a greater number of electrons are being retarded than accelerated, whereby the amount of energy given up to the traveling wave by the electrons at a given instant will be greater than the amount of energy absorbed by the electron beam from the traveling wave. Thus, as the electromagnetic wave travels its helical path from the input coaxial line 39 to the output coaxial line 44, the intensity of the wave energy therein progressively builds up, resulting in a net

amplification for the system, the amplified signal being extracted at coaxial line 44.

Clearly the actual gain obtained by a tube of the type illustrated in Figure 1 is dependent upon numerous factors including the length of the helical wave guide 32 between input and output connectors, the actual velocity differential between the average electron velocity and the axial velocity of the traveling wave. The precise design factors involved in the construction of a tube of this type will not be treated in greater detail in the present application.

The inter-action of the electric field component extending into the cylinder 21 in the region of the electron beam may also be explained by considering the axially moving electrons as encountering electric fields whose magnitudes are continuously increasing as the electrons traverse the cylinder 21 from the electron gun 20 to the collector anode 27.

When considered in this manner, each retarding field will effectively be greater in intensity than the previous accelerating field with the result that electron bunching will occur in the regions of retarding field. As a phenomenon of this type results in the transfer of energy from the beam to the wave, energy will be delivered by the electrons to the electric field to increase further the amplitude of the traveling wave energy. Since the electron velocity in the beam when considered on an average is greater than that of the axial velocity of the traveling electric fields, the electron bunches will not continuously be comprised of the same individual electrons; rather electrons will drift between electron bunches.

The electron tube illustrated in Figure 1 has a particular tendency to become unstable or act as an oscillator unless considerable care is given to the matter of preventing reflections at both ends of the structure. When employed as an amplifier, as in the above description of Fig. 1, it is particularly important to terminate properly and match the wave guide 32 to the external circuits.

On the other hand, if it is desired to operate the electron tube illustrated in Figure 1 as an oscillator for the generation of high frequency electromagnetic wave energy, a feedback circuit delivering energy from the coaxial line 44 to the input terminal of coaxial line 39 of proper phase may be provided. If the gain of the system is comparatively high, then merely mismatching the terminations at input and output connectors will result in self-oscillation at a natural frequency which may be determined by placing suitable frequency sensitive means in the energy input and output coupling systems.

Referring now to Figure 2, there is illustrated a microwave amplifier or oscillator having the general electrical features illustrated and described in connection with Figure 1, but differing somewhat in construction. The electron tube of Figure 2 comprises a glass, or similar dielectric cylinder 61, sealed and evacuated to permit the passage of an electron beam therethrough. Sealed into the left-hand end of cylinder 61, as viewed in Figure 2, is an electron gun comprising an indirectly heated cathode 62, a perforated disc-type grid 63, and focusing and accelerating cylindrical electrodes 64 and 65, respectively. As described in connection with Figure 1, when these electrodes are energized from a suitable power source (not shown), an electron beam is generated having an average electron velocity determined as a function of the total accelerating potential in accordance with the equation set forth above.

The generated electron beam is directed along axis 66 toward a collector electrode 67, suitably sealed into the right-hand end of the cylinder 61. For amplifier and oscillator operation, the potential of collector electrode 67 is determined in a manner similar to that described hereinabove for collector electrode 27 shown in Figure 1.

In accordance with the principles of the present invention, a helical wave guide 71 is coaxially disposed with respect to the glass cylinder 61 and positioned between the ends thereof. Helical wave guide 71 is preferably formed of a coil of unitary U-shaped metallic channel comprising side walls 73 and 74 rigidly spaced by integral outer metallic strip 75. As illustrated the inner open face of this U-shaped channel is formed to lie in the outer surface of cylinder 61.

In order to prevent signal reflections and standing waves within the wave guide 71, helical dissipative blocks 78 and 78' are secured within the ends of this wave guide. As described in connection with the impedance matching blocks 54 of Figure 1, blocks 78 and 78' are preferably uniformly tapered and constituted of a material capable of effectively dissipating microwave energy. The length of a block 78 when measured helically about the guide is greater than a wave length at the lowest frequency of tube operation.

Electromagnetic wave energy is introduced into the wave guide 71 through a coaxial line 76, the outer wall of which enters the wave guide section through a perforation 77 in the outer metallic strip 75. A loop 81 from the coaxial line inner conductor provides ample signal coupling. In a corresponding manner a coaxial cable 82 is utilized to extract signal energy from the wave guide 71. Thus the outer conductor of coaxial cable 82 extends into the wave guide 71 through a perforation 83 therein, and a loop 84 formed of the inner conductor serves as the coupling means.

The outer helical surface of the wave guide 71 is substantially enclosed within a Bakelite or similar insulating cylinder 85, upon which a uniform, solenoid-type coil 86 is wound. When coil 86 is energized from a direct current source (not shown), a magnetic field is established having a large component parallel to the axis 66 of electron travel. This magnetic field minimizes defocusing of the electron beam in its comparatively long axial transit through the cylinder 61 between the electron gun and the collector electrode 67.

Complete structural means for rigidly positioning the elements of the electron tube of Figure 2 in the relation shown have not been illustrated.

The operation of the electron tube illustrated in Figure 2 is essentially similar to that already described in detail in connection with Figure 1. In general when used as an amplifier the weak incoming signal energizes the helical wave guide 71 by means of coupling loop 81. This input signal travels down the helical wave guide 71 in the direction of flow of electrons toward the collector anode 67. The actual axial velocity of the traveling wave is a fraction of the velocity through the wave guide 71 due to the helical path traversed therethrough.

Dissipative blocks 78 and 78' ensure the absence of traveling waves in a direction other than the axial direction of electron flow. Between any two opposed points, such as M and N of the open side of the helical wave guide 71, an electric field is established with a component within the

tube 61 parallel to the axis 66 of the electron flow. This electric field component may be visualized as spinning about the axis of the tube 61 at somewhat less than the velocity of light as the wave travels from left to right as viewed in Figure 2.

The average velocity of electrons entering the space within tube 61 encompassed by the helical wave guide 71 is greater than the axial velocity of the traveling wave. As described above the electron beam is density modulated as it traverses the region of the helical wave guide toward the collector anode 67. In view of the velocity relationships specified for the axial component of the traveling wave and the electron beam, the bunching operation described is accompanied by a general retardation of the beam electrons with the result that energy is delivered from the electron beam to the traveling wave.

As the traveling wave thus approaches the collector anode 67, the energy level thereof is greatly increased whereby the energy delivered to coaxial cable 82 is of considerably higher level than that introduced at coaxial cable 76.

As a result of the separation of individual turns of helical wave guide 71, there are regions as for example between points N and P within the cylinder 61 of comparatively uniformly weak electric field. In other words, the electric field is at all times concentrated between opposed broad walls 73 and 74 of the wave guide. In effect, therefore, regions within the cylinder 61, such as that between points N and P, act as "drift spaces" through which the velocity of electrons remains substantially unaffected.

The electron tube of Figure 2 may be connected for oscillator operation by connecting a portion of the signal output obtained in coaxial cable 82 through proper phasing means to the input coaxial cable 76. For stability of operation, a filter circuit of suitable form (not shown) is preferably connected into the feedback means.

As in the case of the electron tube illustrated in Figure 1, the beam traveling wave tube of Figure 2 is substantially unaffected by signal frequency changes between wide limits or by the band width thereof. It is preferable that the diameter of cylinder 61 be chosen such that when the volume enclosed thereby is considered as a cylindrical wave guide, it has a cut-off frequency above the range of operation of the tube, whereby direct wave propagation and wave reflections at the signal frequency tending to distort the normal electric fields are precluded.

Inter-action with the electron beam of wave energy in the wave guide inter-turn space 88 is highly undesirable. By filling the inter-turn spaces 88 by an absorptive material (not shown) the effect of inter-turn energy may be substantially eliminated. Although an inner-turn space dissipative material has not been illustrated in Figure 2 of the present application, there is illustration and discussion thereof in my aforementioned co-pending patent application.

The electron tubes illustrated in Figures 1 and 2 of the present application are capable of operation as microwave amplifiers or oscillators over extremely wide bands. However, it has been observed that frequency variations alter the strength of the electric fields established between opposed points such as M and N of Figure 2 of the helical wave guide.

The range of operation of the electron tubes of Figures 1 and 2 may be extended considerably in frequency by incorporating wave guide constructions as illustrated in Figures 3 and 4.

Referring now to Figure 3, there is illustrated a portion of an electron tube generally constructed in accordance with the principles illustrated in Figure 1, but modified to include a frequency broadening means.

Thus in Figure 3 there is shown a dielectric cylinder 21 surrounded by an edge-wound helical strip 31 of conductive material which forms a helical channel or wave guide 30 extending through the electron tube. The edge-wound strip 31 is wholly enclosed within a metallic cylinder 33 which in turn is covered by a Bakelite coil-form 52 for the solenoidal coil 51. The components of Figure 3, namely members 21, 31, 33, 51 and 52, function as the correspondingly designated elements of the electron tube of Figure 1.

The sole modification incorporated in the structure of Figure 3 is the addition of a flat helical metallic strip 101. The strip 101 as illustrated in Figure 3 is of a pitch equal to that of the helical strip 31 which defines the sides of helical wave guide 30. Further, the helical gap 102 defined by adjacent turns of helical strip 101 is arranged to be substantially centrally disposed with respect to the edges of the helical strip 31.

It will now be apparent that the helical wave guide 30, Figure 3, is defined between metallic side walls comprising adjacent turns of helical strip 31, a metallic outer side wall as formed by metallic cylinder 33, and an inner metallic wall formed by portions of adjacent turns of helical strip 101 on either side of helical gap 102.

An electromagnetic field established by a traveling wave within the wave guide 30 in turn establishes an electric field directed across the helical gap 102, which field is in effect similar to the field described as formed between points B and G of the electron tube of Figure 1 with the exception of increased intensity.

The field extending across the gap 102 also extends through dielectric cylinder 21 and spins helically as it progresses down the guide between the input and output couplers (not shown in Figure 3).

Electrically the capacitive loading introduced by the helical strip 101 tends to maintain the strength of the electric field existing across the gap substantially constant for wide frequency variations of the input wave energy. As a consequence of this construction, the traveling wave electron tube of Figure 3 is operable over a wider frequency band than the corresponding tube shown in Figure 1. The application of a helical strip such as 101 thus provides a certain design freedom when constructing the wave guide structure 30.

Referring now to Figure 4, there is illustrated in fragmentary form a modification of the electron tube shown in Figure 2 corresponding essentially to the above described modification of the electron tube of Figure 1 as illustrated in Figure 3.

In Figure 4 the dielectric cylinder 61, the helical wave guide 71, the enclosing Bakelite coil form 85, and the solenoid coil 86 correspond to the similarly designated components of the electron tube of Figure 2. Other structural features of Figure 2 have been omitted as they are unessential to the description of the present modification.

To increase the frequency band of operation possible for a beam electron tube of this type, a helically wound flat metallic strip 111 has been positioned upon the outer surface of cylinder 61, and has a pitch corresponding to that of helical wave guide 71. The axial width of the strip 111 is such that, at this pitch, there is provided a uniform

helical air gap 112 between adjacent turns thereof, similar to air gap 102 described in connection with Figure 3.

The air gap 112 which is of helical form is arranged as illustrated in Figure 4 as to lie centralling of the open inner wall of the U-shaped wave guide section 71. It may also be seen that the helical strip 111 completely spans the interturn space 88 between adjacent turns of the wave guide 71.

In operation, traveling wave energy appearing within wave guide 71 establishes a particularly intense electric field across the gap 112 which functions in the manner already described in connection with the traveling fields of Figures 1 and 2, with the advantage that the construction illustrated is operable over a much greater frequency range.

From the foregoing description of the present traveling wave electron tubes, it is apparent that these offer design possibilities unattainable with other known means. Although described above as functioning as signal amplifiers, these tubes may be employed as microwave modulators and detectors, and in other circuits where conventional tube types fail to give the desired performance.

Numerous modifications of the apparatus herein disclosed are possible without departing from the spirit of the present invention. As described, a helical path is employed for signal propagation to reduce the axial velocity of wave propagation to the average electron velocity. A large pitch, necessitating fewer turns for the input and output wave guides, may be used if the wave guides are filled with a solid, low loss dielectric substance. This is possible since the velocity of wave propagation in a solid dielectric is substantially less than the velocity in free space.

In order to increase further the energy output of the tubes illustrated, the helical wave guides may be operated with a uniform increasing potential gradient. Thus, the guides may be formed of a resistive material rather than of highly conductive substances as hereinabove described, and a direct voltage maintained between the ends thereof, the positive end being furthest along in the direction of electron travel. This positive gradient will accelerate and add to the kinetic energy of the electrons, and permit the extraction of increased power from the bunched beam.

It will now also be obvious to those skilled in the art that the inventive principle herein disclosed may, without departure from the invention, take the form in which both the wave guide and electron beam system are enclosed in a common evacuated envelope as illustrated in Figure 3 of the parent application of this application, Serial No. 761,798 filed July 18, 1947.

In view of the many possible structural and electrical design modifications possible, it is preferred that the present invention be defined solely by the appended claims.

I claim:

1. An electron tube comprising an evacuated dielectric cylinder, means for generating an electron beam therein, a helical wave guide formed of channel shaped conductor having substantially rectangular cross-section, a flat helical conductive strip formed in engagement with the outer surface of said dielectric cylinder, the open end of said channel engaging said strip, said strip being formed with adjacent turns spaced from each other so as to effect a helical gap of pitch equal to the pitch of said helical wave guide, said gap being disposed centrally of said open end of said wave guide and permitting energy radiation from said wave guide into the region of said electron beam, and means for introducing energy to and extracting energy from said wave guide.

2. An electron tube comprising an evacuated dielectric cylinder, means for generating an electron beam therein, a helical wave guide formed of channel shaped conductor having substantially rectangular cross-section, a flat helical conductive strip formed in engagement with the outer surface of said dielectric cylinder, the open end of said channel engaging said strip, said strip being formed with adjacent turns spaced from each other so as to effect a helical gap of pitch equal to the pitch of said helical wave guide, said gap being disposed centrally of said open end of said wave guide and permitting energy radiation from said wave guide into the region of said electron beam, and means for introducing energy to and extracting energy from said wave guide, said wave guide being formed to permit inter-action of electromagnetic wave energy flowing therein with said electron beam.

3. An electron tube comprising an evacuated dielectric cylinder, means for generating an electron beam therein, means for directing said beam along a predetermined path, a continuous helical wave guide formed of channel shaped conductor having substantially rectangular cross-section, a flat helical conductive strip formed in engagement with the outer surface of said dielectric cylinder, the open end of said channel engaging said strip, said strip being formed with adjacent turns spaced from each other so as to effect a helical gap of pitch equal to the pitch of said helical wave guide, said gap being disposed centrally of said open end of said wave guide and permitting energy radiation from said wave guide into the region of said electron beam, and wave energy coupling means associated with each end of said wave guide.

4. An electron tube comprising an evacuated dielectric cylinder, means for generating an electron beam therein, means for directing said electron beam along a predetermined path, and a continuous helical wave guide formed of channel shaped conductor having substantially rectangular cross-section, a flat helical conductive strip formed in engagement with the outer surface of said dielectric cylinder, the open end of said channel engaging said strip, said strip being formed with adjacent turns spaced from each other so as to effect a helical gap of pitch equal to the pitch of said helical wave guide, said gap being disposed centrally of said open end of said wave guide and permitting energy radiation from said wave guide into the region of said electron beam, said wave guide being formed to permit inter-action of electromagnetic wave energy flowing therein with said electron beam, and said wave guide having energy input and output couplings displaced longitudinally of said path.

5. An electron tube comprising an evacuated dielectric cylinder, means for generating an electron beam therein, means for directing said electron beam over a substantially linear path, a wave guide of substantially rectangular cross-section helically wound around said beam path, a flat helical conductive strip formed in engagement with the outer surface of said dielectric cylinder, the open end of said guide engaging said strip, said strip being formed with adjacent turns spaced from each other so as to effect a helical gap of pitch equal to the pitch of said heli-

cal wave guide, said gap being disposed centrally of said open end of said wave guide and permitting energy radiation from said wave guide into the region of said electron beam, said wave guide being adapted to permit density modulation of said electron beam in accordance with electric wave energy flowing therein, and to extract energy from a density modulated electron beam.

6. A beam traveling wave electron tube comprising in combination an evacuated dielectric cylinder, an electron gun disposed at an end of said cylinder for generating an electron beam of predetermined average electron velocity, a collector electrode positioned within the opposed end of said dielectric cylinder, means for directing said generated electron beam axially through said dielectric cylinder and impinging said beam upon said collector electrode, a helical wave guide formed of channel shaped conductor having substantially rectangular cross-section, a flat helical conductive strip formed in engagement with the outer surface of said dielectric cylinder, the open end of said channel engaging said strip, said strip being formed with adjacent turns spaced from each other so as to effect a helical gap of pitch equal to the pitch of said helical wave guide, said gap being disposed centrally of said open end of said wave guide and permitting energy radiation from said wave guide into the region of said electron beam, and means for introducing and extracting energy from said wave guide.

7. An electron tube comprising an evacuated dielectric cylinder, means for generating an electron beam therein, a helical waveguide of substantially rectangular cross-section having one of its conductive bounding surfaces in engagement with the outer surface of said dielectric cylinder, said one bounding surface being provided with a gap running lengthwise thereof and following the helical convolutions of said surface, said gap being disposed centrally of said one bounding surface and permitting energy radiation from said waveguide into the region of said electron beam, and means for introducing energy to and extracting energy from said waveguide, the axial dimension of said gap being less than the axial dimension of the cross-section of said wave guide.

8. A beam traveling wave electron tube comprising in combination an evacuated dielectric cylinder, an electron gun disposed at an end of said cylinder for generating an electron beam of predetermined average electron velocity, a collector electrode positioned within the opposed end of said dielectric cylinder, means for directing said generated electron beam axially through said dielectric cylinder and impinging said beam upon said collector electrode, a helical waveguide of substantially rectangular cross-section having one of its conductive bounding surfaces in engagement with the outer surface of said dielectric cylinder, said one bounding surface being provided with a gap running lengthwise thereof and following the helical convolutions of said surface, said gap being disposed centrally of said one bounding surface and permitting energy radiation from said waveguide into the region of said electron beam, and means for introducing energy to and extracting energy from said waveguide, the axial dimension of said gap being less than the axial dimension of the cross-section of said wave guide.

9. A beam traveling wave electron tube comprising in combination an evacuated dielectric cylinder, an electron gun disposed at an end of said cylinder for generating an electron beam of predetermined average electron velocity, a collector electrode positioned within the opposed end of said dielectric cylinder, means for directing said generated electron beam axially through said dielectric cylinder and impinging said beam upon said collector electrode, a helical waveguide of substantially rectangular cross-section having one of its conductive bounding surfaces in engagement with the outer surface of said dielectric cylinder, said one bounding surface being provided with a gap running lengthwise thereof and following the helical convolutions of said surface, said gap being disposed centrally of said one bounding surface and permitting energy radiation from said waveguide into the region of said electron beam, and means for introducing energy to and extracting energy from said waveguide, said waveguide being adapted to permit density modulation of said electron beam in accordance with electric wave energy flowing therein, and to extract energy from a density modulated electron beam, the axial dimension of said gap being less than the axial dimension of the cross-section of said wave guide.

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