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TRAVELING-WAVE TUBE

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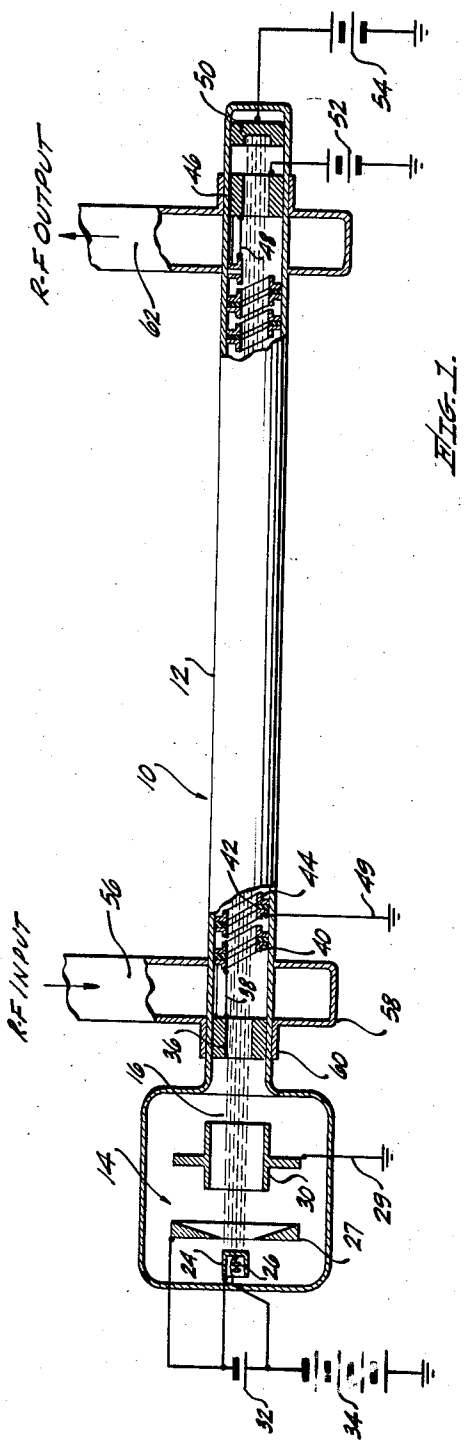


FIG. 1.

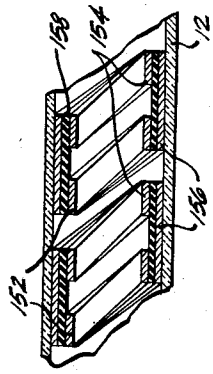


FIG. 5.

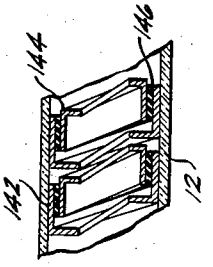


FIG. 4.

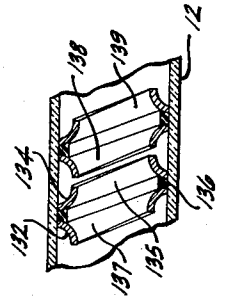


FIG. 3.

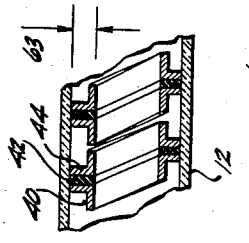


FIG. 2.

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TRAVELING-WAVE TUBE

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14 Claims. (Cl. 315—3.6)

This invention relates to microwave tubes and more particularly to a slow-wave structure which may be employed to focus the electron stream of a traveling-wave tube.

In a typical traveling-wave tube a conductive helix is employed to propagate an electromagnetic wave at a velocity substantially less than the velocity of light. An electron stream is then projected through the helix to interact with the wave and to cause the wave to "grow" or be amplified. An axial magnetic field is normally provided by a solenoid which is disposed concentrically about the helix. The use of this solenoid unduly restricts the scope of applications to which a traveling-wave tube may be put. This is true because the relative cost, size, weight and power consumption of the solenoid are unfavorably high.

Recently a bifilar helix has been employed to focus the electron stream of a traveling-wave tube utilized as a so-called backward-wave oscillator as described by P. K. Tien, "Bifilar Helix for Backward-Wave Oscillators," Proc. I. R. E., vol. 42, pp. 1137–1143 (1954). Two parallel helices are maintained at different direct-current potentials in this type of tube to produce a plurality of electrostatic electron lenses. The gain of a forward wave, which travels in the direction of the electron stream, is proportional to the forward-wave impedance of the slow-wave structure on which it is propagated. Likewise, the gain of a backward wave, which is propagated in the opposite direction, is proportional to the backward-wave impedance of the slow-wave structure on which it is propagated. It has been found that the backward-wave impedance of a bifilar helix is relatively high whereas the forward-wave impedance is relatively low. Such a slow-wave structure has undoubted utility in a backward-wave oscillator; however, any forward-wave amplification is substantially prevented by backward-wave oscillations occurring in this tube.

It is therefore an object of the invention to provide means for electrostatically focusing the electron stream of a traveling-wave tube amplifier.

It is another object of the invention to provide means for focusing the electron stream of a traveling-wave tube amplifier whereby the use of a focusing solenoid may be eliminated.

By practicing the present invention, the electron stream focusing advantage of a bifilar helix may be obtained without its high impedance to backward waves. A traveling-wave tube embodying the present invention may thus be effectively employed as an amplifier. In accordance with the present invention, the tube comprises two parallel conductive helices and means for maintaining the two separate conductive helices at different direct-current potentials while producing an alternating-current coupling along the entire length of the two helices. The helices thus appear to be bifilar to the steam electrons and unifilar to microwaves. A unifilar helix of reasonable dimensions has a relatively high forward-wave impedance and a relatively low impedance to the backward wave. Consequently, backward-wave self-oscillation is effectively suppressed.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawing in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only, and is not intended as a definition of the limits of the invention.

Fig. 1 is a sectional view of an amplifier tube embodying the present invention together with associated circuitry;

Fig. 2 is an enlarged broken away section of the slow-wave structure of the amplifier of Fig. 1; and

Figs. 3, 4 and 5 are broken away sections of alternative embodiments of the slow-wave structure of the invention.

Referring to Fig. 1, there is shown a traveling-wave amplifier **10** for amplifying microwave signals comprising an elongated evacuated envelope **12** having an enlarged portion at the left extremity thereof, as viewed in Fig. 1, for housing an electron gun **14**. Electron gun **14** produces a stream of electrons which is directed along a predetermined path **16** that lies on the longitudinal axis of elongated envelope **12**.

Gun **14** comprises a cathode **24** with a heater **26**, a focusing electrode **27** and an accelerating anode **30**. Heater **26** is connected in series with a source of potential **32** and cathode **24**. Cathode **24** is referenced to a potential considerably below ground by a source of potential **34** having its positive terminal grounded. Cathode **24** and focusing electrode **27** are both connected to the negative terminal of potential source **32**. A voltage of the order of 1000 volts negative with respect to ground is representative of the voltage normally impressed upon cathode **24** by source **34**. Focusing electrode **27** has a frustro-conical inner surface which is disposed at an angle of 67½ degrees with respect to its axis of revolution. Accelerating anode **30** is maintained at ground potential to accelerate electrons emitted by cathode **24**.

Proceeding along from the electron gun **14** in the direction of electron flow, there are positioned successively about the electron stream path **16** a matching ferrule **36** connected by an antenna-type lead **38** to a helical conductor **40** having a substantially L-shaped cross section, a helical dielectric ribbon or strip **42** having a rectangular cross section disposed contiguous to conductor **40**, and a helical conductor **44** also having a substantially L-shaped cross section and being disposed contiguous to the dielectric strip **42**. One leg of each L of the conductors **40** and **44** lies radially about the axis or path of electron flow while the other leg of each conductor lies axially along the path. The helical conductors are disposed back-to-back whereby the radial legs are substantially parallel to each other throughout their length and are separated by the helical dielectric ribbon **42**. At the right end of the envelope **12** helical conductor **44** is connected over a lead **48** to an output ferrule **46**.

A collector electrode **50** is positioned at the end of the path **16** to intercept and collect the stream electrons. Helix **40** is maintained at ground potential by a suitable connection **49** thereto and helix **44** is maintained a few hundred volts positive with respect to ground by a source **52** which is connected between ferrule **46** and ground. Alternatively, the potential of helix **44** may be lower than that of helix **40**.

Collector electrode **50** is maintained at a potential of the order of 300 volts positive with respect to the potential of ferrule **46** in order to prevent the return of

secondary electrons thereto. This is accomplished by a connection to the positive terminal of a battery 54, the negative terminal of which is connected to ground.

An input to the tube 10 is provided by an input waveguide 56 which symmetrically encloses a portion of envelope 12 that is coextensive with the lead 38. Waveguide 56 has a shorted termination 58 located an odd multiple of a one-quarter guide wavelength therefrom in order to effect optimum coupling from the waveguide 56 to the lead 38 and hence to helices 40 and 44. A sleeve 60 is disposed concentrically about envelope 12 coextensively with ferrule 36. Sleeve 60 is electrically connected to the side of waveguide 56 nearest the electron gun 12. Both ferrule 36 and sleeve 60 are of an appropriate length to produce a virtual shorting plane on the left inner surface of waveguide 56 so that substantially all energy is directed along the helices for modulating the electron stream. Waveguide 56 is preferably maintained near ground potential in order not to disrupt the flow of electrons. The same is true of an output waveguide 62 which is similarly positioned about envelope 12 as is conventional.

A material such as tungsten or molybdenum is suitable for making the helices 40, 44, the principal requirement being that they retain their form, especially with respect to the ratio of their pitch to their diameter.

Dielectric material 42 should have a relative dielectric constant which is substantially greater than unity in order to produce a satisfactory alternating-current coupling between helices 40, 44. Helices 40, 44, which serve as a slow-wave circuit for traveling-wave tube 10, preferably have an inner diameter substantially equal to the inner diameter of ferrules 36 and 46 so that the stream electrons can be made to pass as close to the helices as possible without being intercepted by them. The distance 63 corresponding to the radial thickness of the L-shape portion of helices 40, 44 shown in Fig. 2 is preferably equal to

$$\frac{n\lambda g}{4}$$

where λg is a wave guide wavelength corresponding the mid-frequency of the operating band of the tube 10 and n is any positive odd integer. When the slow-wave circuit is constructed in this manner a virtual shorting plane is produced at the inner diameter of helices 40, 44 which makes them appear as a unifilar or single conductor helix to microwaves. The pitch of helices 40, 44 may be substantial in comparison to their diameter. The smaller their diameter is made, the better the electron stream focusing effect that may be obtained. This is true because in this way the electrostatic focusing field between the helices "protrudes" farther into the electron stream path.

When a dielectric such as the helix 42 is interposed between two conductors such as helices 40, 44 which are maintained at different direct-current potentials, the electric field external to the dielectric and the conductors is weakened. The strengthening of the alternating-voltage coupling of the two helical conductors 40, 44 provided by the dielectric material 42 thus weakens the electrostatic focusing field in the present invention and requires that potentials having a relatively high difference be applied to the conductive helices.

In the operation of the tube 10, electron gun 14 produces a stream of electrons which is directed along the path 16 into the helices 40, 44. Since the helices 40, 44 are maintained at different direct-current potentials, equipotential lines encircle each of the turns of the helices. The stream then expands and contracts as it is directed through the helices because electrons tend to travel perpendicularly to the circling equipotential lines. The stream is thus effectively focused by the equivalent of a plurality of electrostatic electron lenses. A traveling-wave is then launched along the helix 40 by the microwave signal impressed on input wave pitch 56. Both helices 40, 44 then propagate the wave as single helix. This is true for two reasons. Firstly, because the dielectric strip 42 provides a capacitive coupling between the helices and secondly, because the helices are constructed so that the distance 63 is equal to

$$\frac{n\lambda g}{4}$$

whereby the helices 40, 44 are virtually shorted at their inner diameters. The focused electron stream is permitted to interact with the launched wave and this interaction produces a substantial amplification of the wave; however, backward-wave self-oscillation is inherently absent because the combination of structure of the helices 40, 44 and dielectric strip 42 propagate microwaves with the same electromagnetic properties as a single conductive helix.

Figs. 3, 4 and 5 are intended to illustrate a few of the many different structures which may be employed to focus an electron stream and to provide a slow-wave structure electrically equivalent for alternating currents to a single conductive helix. In Fig. 3 a pair of helixes 132, 134 is shown having an arc-shaped cross section. Helices 132, 134 are disposed concentrically within the envelope 12. A helical dielectric strip 136 is disposed between the adjacent radial extremities of the helices 132, 134 to provide an alternating-current coupling therebetween.

In Fig. 4 another pair of helices 142, 144 are shown disposed within the envelope 12. Helices 142, 144 both have an inverted L-shaped cross section with their portions at right angles to the tube envelope extending toward the electron stream and the helix 144 is disposed concentrically within a portion of the helix 142. A dielectric strip 146 is disposed between the helices 142, 144 inside of helix 142 and contiguous to the outer surface of the helix 144.

In Fig. 5 a wide metallic helical tape or strap 156 is shown disposed concentrically within the envelope 12. Helical tape 156 is employed with a dielectric tape 158, which is disposed contiguous to the inner surface of helix 156, to electrically couple a pair of metallic helical tapes 152 and 154. The metallic helical tapes 152, 154 are disposed contiguous to the inner surface of dielectric tape 158 at the opposite axial extremities of each turn of the dielectric tape 158. The metallic helical tapes 152, 154 may thus be maintained at different direct-current potentials to focus the electron stream, but they propagate microwaves in a manner electrically equivalent to that of a single conductive helix. The use of the wide metallic helical tape 156 may alternatively be omitted in cases where the dielectric tape 158 provides a satisfactory alternating-current coupling between the metallic helical tapes 152, 154.

What is claimed is:

1. A traveling-wave tube comprising an electron gun for producing an electron stream, means for directing said stream along a predetermined path, two parallel conductive helices disposed about said path for propagating electromagnetic waves, and a helical dielectric strip disposed contiguous to and intermediate said helices along substantially their entire length for coupling electromagnetic energy from one of said conductive helices to the other in a manner whereby the electromagnetic energy may be propagated along said helices as though along a single helix.

2. A traveling-wave tube comprising an electron gun for producing an electron stream, means for directing said stream along a predetermined path, two parallel conductive helices disposed concentrically about said path for propagating electromagnetic waves at a velocity substantially less than the velocity of light, means for maintaining said helices at different direct-current potentials to focus said stream electrostatically, and a helical dielectric

strip disposed contiguous to and intermediate said helices for coupling electromagnetic energy from one of said helices to the other, whereby said conductive helices are effectively one unifilar helix.

3. A traveling-wave tube comprising an evacuated envelope, an electron gun disposed at one end of said envelope for producing an electron stream, means for directing said stream along a predtermined path, two parallel helical conductors having substantially L-shaped cross sections disposed about said path for propagating electromagnetic waves at a velocity substantially less than the velocity of light, a dielectric material disposed contiguously between adjacent radial portions of said helical conductors for coupling electromagnetic energy from one of said conductors to the other, whereby said helical conductors are effectively one unifilar helix, and means for maintaining said conductors at different direct-current potentials to focus said stream electrostatically.

4. The traveling-wave tube as defined in claim 3, wherein said conductors have a radial thickness equal to

$$\frac{n\lambda g}{4}$$

where n is any positive odd integer and λg is the waveguide wavelength of a wave having a frequency equal to the mid-frequency of the operating band of said tube.

5. A traveling-wave tube comprising an evacuated envelope, an electron gun disposed at one end of said envelope for producing an electron stream, means for directing said stream along a predetermined path, two parallel helical conductors for propagating electromagnetic waves at a velocity substantially less than the velocity of light, said conductors having arcuate cross sections, a helical strip of a dielectric material disposed between adjacent radial extremities of said conductors for coupling electromagnetic energy from one of said helical conductors to the other, whereby said helical conductors form effectively one unifilar helix, and means for maintaining said conductors at different direct-current potentials to focus said stream electrostatically.

6. A traveling-wave tube comprising an evacuated envelope, an electron gun disposed at one end of said envelope for producing an electron stream, means for directing said stream along a predetermined path, two parallel helical conductors having substantially L-shaped cross sections disposed concentrically about said path for propagating electromagnetic waves at a velocity substantially less than the velocity of light, one of said helical conductors being disposed within the other, a helical tape of a dielectric material disposed between adjacent axial portions of said conductors for coupling electromagnetic energy from one of said conductors to the other, whereby said two helical conductors propagate the electromagnetic waves as along a single unifilar helix, and means for maintaining said conductors at different direct-current potentials to focus said stream electrostatically.

7. A traveling-wave tube comprising an evacuated envelope, an electron gun disposed at one end of said envelope for producing an electron stream, means for directing said stream along a predetermined path, two bifilar helical conductive tapes disposed concentrically about said path for propagating electromagnetic waves at a velocity substantially less than the velocity of light, a helical dielectric tape disposed externally to and coextensive with each pair of turns of said conductive tapes for coupling electromagnetic energy from one of said conductive tapes to the other, whereby said helical conductive tapes form effectively one unifilar helix, and means for maintaining said conductive tapes at different direct-current potentials to focus said stream electrostatically.

8. The traveling-wave tube as defined in claim 7, wherein a helical conductive tape having a width equal to that of said dielectric tape is disposed contiguously about said dielectric tape.

9. A traveling-wave tube comprising an electron gun for producing an electron stream, means for directing said stream along a predetermined path, and a conductive unifilar type helix disposed concentrically about said path for propagating electromagnetic waves, said helix comprising two closely spaced helical conductors and a relatively thin helical dielectric ribbon separating said conductors, said conductors being thereby electromagnetically capacitively coupled substantially throughout their length, whereby said two helical conductors are effectively a single, unifilar radio frequency conductor.

10. A traveling-wave tube comprising an electron gun for producing an electron stream, means for directing said stream along a predetermined path, a conductive unifilar type helix disposed concentrically about said path for propagating electromagnetic waves, said helix comprising two closely spaced helical conductors and a thin helical dielectric ribbon separating said conductors, whereby said two helical conductors propagate the electromagnetic waves as along a single unifilar helix, and means for maintaining said two helical conductors at different direct current potentials.

11. In a traveling-wave tube of the character utilizing an electron stream for amplifying electromagnetic waves propagated therealong, a conductive helix for electrostatically focusing said electron stream along a predetermined path and for propagating radio frequency electromagnetic waves axially along said path, said conductive helix comprising two helical conductors closely spaced and separated by a helical dielectric ribbon along substantially their entire length whereby the two helical conductors are effectively one unifilar conductive helix for radio frequency waves propagated therealong.

12. In a traveling-wave tube of the character utilizing an electron stream for amplifying electromagnetic waves propagated therealong, a conductive helix for electrostatically focusing said electron stream along a predetermined path and for propagating radio frequency electromagnetic waves axially along said path, said conductive helix comprising two helical conductors closely spaced and separated by a helical dielectric ribbon along substantially their entire length whereby the two helical conductors are effectively one unifilar conductive helix for radio frequency waves propagated therealong, and means for maintaining said two helical conductors at different direct current potentials for focusing said electron stream along said predetermined path.

13. The invention as set forth in claim 12 in which said helical conductors have L-shaped cross-sections and are disposed so that a first leg of each L lies radially about said path while a second leg lies axially about said path, said helical conductors being disposed back-to-back whereby said first legs are substantially parallel to each other throughout their length and are separated by said helical dielectric ribbon.

14. The invention as set forth in claim 13 in which the radial width of said helical conductors and dielectric ribbon is

$$\frac{n\lambda g}{4}$$

where n is any positive odd integer and λg is the waveguide wavelength of an electromagnetic wave having a frequency equal to the mid-frequency of the operating band of said tube.

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