Jan. 12, 1960 C. K. BIRDSALL 2,921,223

HIGH-POWER TRAVELING-WAVE TUBE

Filed Nov. 15, 1954

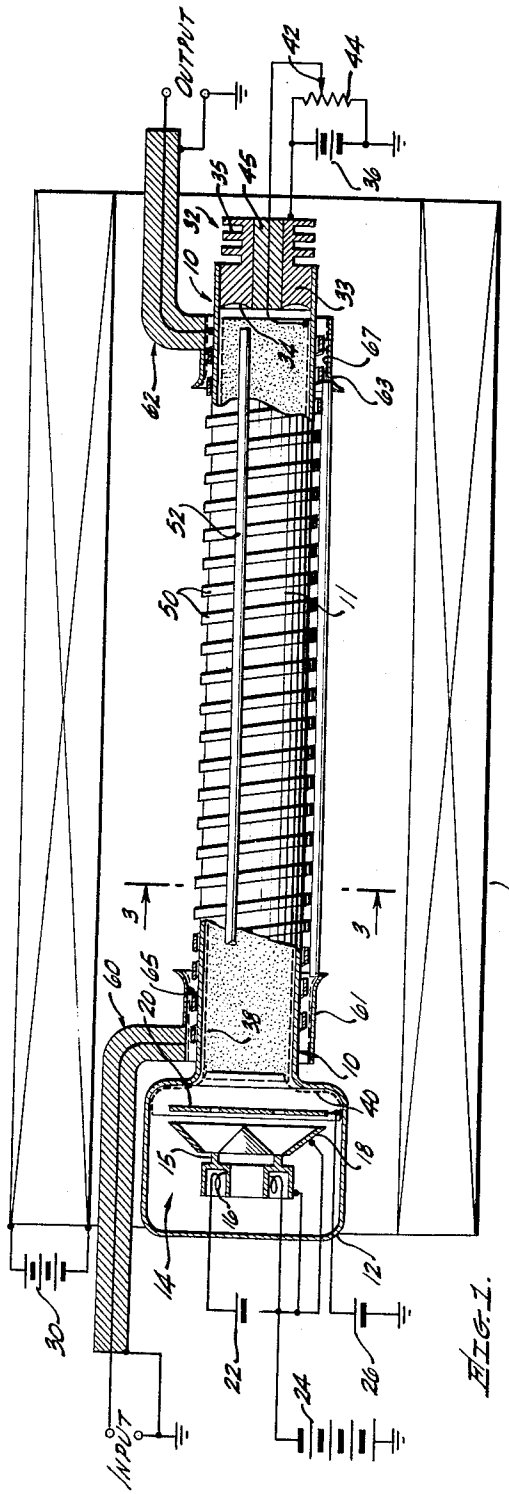


FIG. 1.

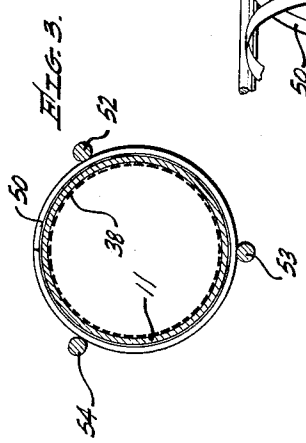


FIG. 3.

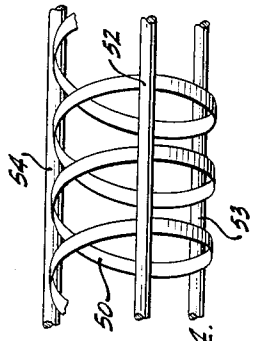


FIG. 4.

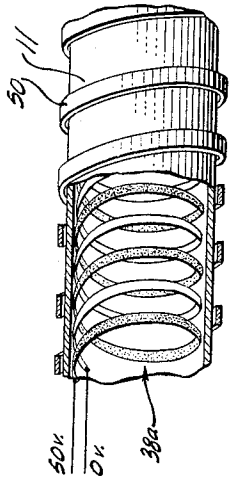


FIG. 2.

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HIGH-POWER TRAVELING-WAVE TUBE

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4 Claims. (Cl. 315—3.5)

This invention relates to microwave tubes and more particularly to a traveling-wave tube capable of providing a high-power output signal within a selected portion of the frequency spectrum.

As is generally known, an electron stream will interact with an electromagnetic wave when the electron stream has a velocity that is in "synchronism" with the phase velocity of the wave. For a particular set of circumstances, the electron stream has an optimum synchronous velocity whereby maximum energy is transferred from the electron stream to the wave. When the electron stream is flowing in an equipotential region inherent in slow-wave propagating structures, this diminution of energy in the electron stream results in a concomitant decrease in its overall velocity. As the velocity of the electron stream decreases from the optimum synchronous velocity, less energy is transferred from the stream to the electromagnetic wave resulting in less efficient operation of the traveling-wave tube. In a conventional traveling-wave tube, attempts have been made to increase the operating efficiency by progressively decreasing the velocity of the electromagnetic wave propagated by the slow-wave structure. For the most part, it is impracticable to make structures of this type to the tolerances required in travling-wave tubes.

In accordance with the present invention, an electron stream "pencil" is provided that is independent of a slow-wave propagating structure such as, for example, a folded waveguide or helix normally used in conjunction with wave-type amplifier tubes. By means of an independent electrostatic field produced in the region occupied by the electron stream by impressing appropriate potentials across a resistive coating on the inner surface of an elongated glass cylinder, the velocity of the electron stream may be made independent of the slow-wave propagating structure so as to effect maximum power transfer from the stream to an electromagnetic wave to be amplified. In addition, this resistive coating may be made to have a bifilar helical configuration and potentials impressed thereon to focus the electron stream. Thus eliminating the need for the magnetic solenoid normally used for electron stream focusing together with its concomitant alignment difficulties.

In addition to the above, the fabrication of the slow-wave structure is simplified to the extent that any metal may be used without regard to its behavior within a vacuum. For example, it is generally realized that tungsten or molybdenum normally used for helical structures is very difficult to machine. Further, in the event that a helix is employed for the slow-wave propagating structure, having the envelope inside the helix adapts the device to the use of close-fitting exponential horns as transitional devices between coaxial line input and output leads to the tube. In this manner, a good impedance match to and from the tube over a broad range of frequencies is achieved without the necessity of using intermediate coupling helices as are presently required when

using this type of impedance matching device with a conventional traveling-wave tube.

It is therefore an object of the present invention to provide a traveling-wave device incorporating apparatus capable of controlling the velocity of the electron stream independently of its slow-wave structure.

Another object of the present invention is to provide a high-power traveling-wave tube capable of being operated within diffierent portions of the frequency spectrum.

Still another object of the present invention is to provide a traveling-wave tube incorporating a simple structure capable of providing an impedance match to its slow-wave propagating structure over a broad range of frequencies.

A further object of the present invention is to provide a traveling-wave tube incorporating a helix capable of being operated at potentials independently of that of the tube thereby enabling the electron stream to be focused by electrostatic means.

A still further object of this invention is to provide a more versatile traveling-wave tube for experimental use having interchangeable helices.

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 diagrammatic sectional view of an embodiment of the traveling-wave tube of the invention together with associated circuitry;

Fig. 2 shows an enlarged portion of an alternative type of resistive coating on the inner surface of the elongated cylindrical portion of the evacuated envelope of the tube of Fig. 1;

Fig. 3 is a cross sectional view of section 3—3 of Fig. 1; and

Fig. 4 is a view in perspective of the helix with its ceramic rod supports as viewed independently of the tube of Fig. 1.

Referring now to Fig. 1, there is shown a diagrammatic sectional view of the traveling-wave amplifier tube of the present invention. An envelope **10**, which provides the necessary evacuated chamber, consists of an elongated cylindrical portion **11** with an enlarged portion **12** at its left extremity, as viewed in the figure. Within the enlarged portion **12** of envelope **10**, there is disposed an electron gun **14** which may produce, for example, a hollow cylindrical electron stream. Electron gun **14** comprises an annular cathode **15** with a heater **16**, a focusing electrode **18**, and an accelerating electrode **20**, the electrodes **18** and **20** being provided with apertures disposed in alignment with the electron emitting surface of cathode **15** which may have a conical central projection as shown to allow passage therethrough of the electron stream.

The electron emitting surface of cathode **15** has an outer diameter slightly less than the inner diameter of the elongated cylindrical portion **11** of envelope **10**. Cathode **15** is disposed with its electron emitting surface in a plane normal to and concentrically about the longitudinal axis of envelope **10**. Heater **16** of cathode **15** is energized by means of a connection across a source of potential, such as a battery **22**, one terminal of which is connected to cathode **15**, as shown. The focusing electrode **18**, disposed adjacent to and to the right of the cathode **15**, as shown in the figure, has an inner and an outer surface of revolution about the longitudinal axis of

envelope 10 and at an acute angle therewith to provide focusing for the electron stream. Cathode 15 and focusing electrode 18 are connected together and are, in turn, connected to the negative terminal of a source of potential such as a battery 24, the positive terminal of which is connected to ground. The potential provided by battery 24 may be of the order of −2000 volts with respect to ground. Last, the accelerating electrode 20 of electron gun 14 is maintained at a potential that is positive with respect to the potential of cathode 15 by means of a battery 26 interconnected between electrode 20 and ground. The potential provided by battery 26 is of the order of 300 volts.

A solenoid 28 is positioned concentrically about the complete length of envelope 10. An appropriate direct current is made to flow through solenoid 28 by means of connections across the terminals of a battery 30 to produce a magnetic field of the order of 600 gauss that extends longitudinally along the tube. The purpose of this magnetic field is to keep the electron stream forcused or constrained throughout the active length of the tube.

A collector electrode 32 for intercepting and collecting the electron stream is sealed to the extremity of the elongated cylindrical portion 11 farthest from the electron gun 14. Collector electrode 32 comprises an annular metal portion 33 having a concave surface 34 of circular cross-section disposed so as to intercept the electron stream. In addition, electrode 32 includes several metallic discs 35 attached to a tubular extension from the portion 33 for dissipating the heat produced by the interception of the stream electrons. The collector electrode 32 when sealed to the elongated cylindrical portion 11 of envelope 10 has no portion that extends radially outwards past the cylindrical portion 11. In the operation of the tube, the collector electrode 32 is maintained at a potential of the order of +300 positive with respect to ground by means of a connection therefrom to a battery 36, the negative terminal of which is referenced to ground.

A resistive coating 38 is disposed on the inner surface of the elongated cylindrical portion 11 of the envelope 10 and extends from the junction between the enlarged portion 12 and the elongated portion 11 of envelope 10 to just short of the collector electrode 32. The resistance of resistive coating 38 must be sufficiently high so as not to attenuate signals propagated by the electron stream that exist along the length of the tube but, on the other hand, must be sufficiently low so as to maintain a progressively more positive electrostatic field that predominates the region occupied by the electron stream between the electron gun 14 and the collector electrode 32. Accordingly, the resistance of resistive coating 38 may be of the order of 100,000 ohms/square, this term specifying the measure of area resistance taken along the plane of the area, not perpendicular thereto, the measure being thus independent of the magnitude of the area considered. Under normal conditions, a coating having this resistivity will only be required to dissipate of the order of 25 milliwatts. Resistive coatings of this type may be provided, for example, by a coating of stannous oxide on the glass constituting the envelope 10.

In order to maintain a progressively more positive electrostatic field along the path of the electron stream, it is necessary to impress different potentials at each extremity of resistive coating 38. Accordingly, a conductive coating 40 is disposed on the inner surface of the envelope 10 commencing from the focusing electrode 18 of gun 14 and extending along the tube until it overlaps a portion of the resistive coating 38. During the operation of the tube, this extremity of the resistive coating 38 is maintained at ground potential by means of a connection therefrom to the conductive coating 40 and hence to ground.

The extremity of resistive coating 38 farthest from electron gun 14, on the other hand, is maintained at an adjustable potential of the order of 100 volts positive with respect to ground. This is accomplished by a connection from the resistive coating 38 through a hole in the center of collector electrode 32 to a tap 42 of a potentiometer 44 which is, in turn, connected across battery 36. A glass seal 45 is disposed in the hole through collector 32 to insulate the lead therethrough from the collector 32 and seal the evacuated chamber.

Referring to Fig. 2, there is illustrated an improved form of resistive coating 38*a* that may be employed in conjunction with the present invention. Resistive coating 38*a* constitutes a conductive coating of helical configuration disposed on the inner surface of the elongated cylindrical portion 11 of envelope 10. Coating 38*a* has a sufficient number of turns per inch so that substantially no axial current flows which would attenuate a signal propagated by the electron stream. A potential gradient is maintained across the conductive coating 38*a* in the same manner as with resistive coating 38 by means of connections to conductive coating 40 and to tap 42 of potentiometer 44.

In the event that it is desired to employ electrostatic focusing of the electron stream, the coating 38*a* may constitute a bifilar helix with different potentials being impressed on the separate helices to effect the desired focusing as indicated in Fig. 2. This method of focusing an electron stream appears in an article entitled, "Bifilar Helix for Backward-Wave Oscillators," by Ping King Tien, published in vol. 42 of the Proceedings of the I.R.E. for July 1954. It is to be noted that inasmuch as the resistive coating 38*a* in the present device is not used as a wave propagating structure, that electrostatic focusing of the electron stream is not necessarily restricted to backward-wave oscillator operation.

The slow-wave structure for propagating an electromagnetic wave is provided, for example, by a conductive helix 50 disposed on the outside of the elongated cylindrical portion 11 of evacuated envelope 10. The helix 50 extends contiguously along the cylindrical portion 11 coextensively with the resistive coating 38 or 38*a*. Helix 50 may be fabricated of any desired type of metal, the main prerequisite being that it retain its form, especially with respect to its pitch and diameter. In that the helix 50 may be slid on and off the cylindrical portion 11 of envelope 10 over the collector electrode 32, it is possible to employ a number of helices or folded waveguide structures having different characteristics with the tube of the present invention. For example, helices of different pitch for optimum operation within selected frequency ranges, and helices having different amounts of attenuation or stop-bands to avoid backward-wave oscillations may be employed. In order that the turns of the helix 50 be retained in the desired relationship with respect to each other, three ceramic rods 52, 53 and 54 extending along substantially the entire length of the helix are disposed at equal intervals about its outer periphery, as shown particularly in Figs. 3 and 4. Rods 52, 53 and 54 may be attached to each turn of the helix 50 by glazing them thereto.

An input to the tube is provided by an input coaxial section 60 connected between the "input" terminals and the turn of helix 50 nearest electron gun 14, and an output from the tube is provided by an output coaxial section 62 connected from the last turn at the opposite extremity of helix 50 to the "output" terminals. The impedance of the coaxial sections 60, 62 is made to match that of the helix over a broad band of frequencies by ferrules 61, 63 which are disposed contiguously about the first and last several turns of the helix 50, respectively. The adjacent extremities of ferrules 61, 63 are made to expand exponentially outwards to improve the transition to and from helix 50. In general, to effect a good transition over a broad range of frequencies, the spacing between the inner surface of ferrules 61, 63 and the outer periphery of helix 50 should be of the order of 10% of the spacing

in the coaxial line employed. This spacing may be maintained by thin layers of insulation 65, 67 disposed between the ferrules 61, 63, respectively, and helix 50. The helix 50 may be maintained at any potential that may be conveniently employed with the apparatus associated with the tube.

In the operation of the tube of the present invention, the potential of cathode 15 is adjusted with respect to the potential impressed on conductive coating 40 so that the initial velocity of the electron stream through helix 50 produces maximum power output from the tube. The velocity at which this occurs will, of course, depend on the pitch and other characteristics of the helix employed. Secondly, the tap 42 of potentiometer 44 is adjusted so that optimum maximum power output is obtained. If desired, the helix 50 may be readily interchanged with another helix or other slow-wave propagating structure so as to achieve optimum operation within a different frequency range.

What is claimed is:

1. A traveling-wave tube comprising an evacuated envelope including an elongated cylindrical portion, an electron gun within said envelope for producing an electron stream, bifilar helical resistive coatings substantially transparent to microwaves disposed on the inner surface of said envelope coextensive with at least a portion of said elongated portion, means for impressing different predetermined potentials on said bifilar coatings to electrostatically focus said electron stream along a predetermined path within said elongated portion of said envelope, and a slow-wave structure disposed on the outside of said envelope along a substantial portion of said path to propagate an electromagnetic wave therealong at a velocity whereby energy is transferred from said electron stream to said wave.

2. A traveling-wave tube comprising an evacuated envelope having an elongated cylindrical portion, an electron gun disposed within said envelope for producing a

cylindrical electron stream, means for directing said electron stream along a predetermined path extending along the inner surface of said elongated portion of said envelope, a helix disposed contiguously along the outside of said elongated portion of said envelope coextensive with at least a portion of said predetermined path for propagating an electromagnetic signal wave therealong at a velocity whereby energy is transferred from said electron stream to said wave thereby progressively decreasing the velocity of said electron stream, a resistive coating substantially transparent to said electromagnetic signal wave disposed on the inner surface of said elongated portion of said evacuated envelope, means providing a potential gradient along said resistive coating to produce a progressively more positive electrostatic field in the direction of electron flow within the region occupied by said electron stream to maintain the average kinetic energy thereof at a value to effect optimum amplification of said signal wave.

3. The traveling-wave tube as defined in claim 2 wherein the resistance of said resistive coating is greater than 100,000 ohms per square.

4. The traveling-wave tube as defined in claim 2 wherein said resistive coating along the inner surface of said elongated portion of said envelope has a helical configuration.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,921,223 January 12, 1960

Charles K. Birdsall

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 36, after "+300" insert -- volts --; line 47, after "tube" insert -- (that is, the coating 38 must be substantially transparent to microwaves) --.

Signed and sealed this 7th day of June 1960.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents