Nov. 4, 1958 G. R. BREWER 2,859,375

MULTIFILAR HELIX COUPLING

Filed Aug. 4, 1955 2 Sheets-Sheet 1

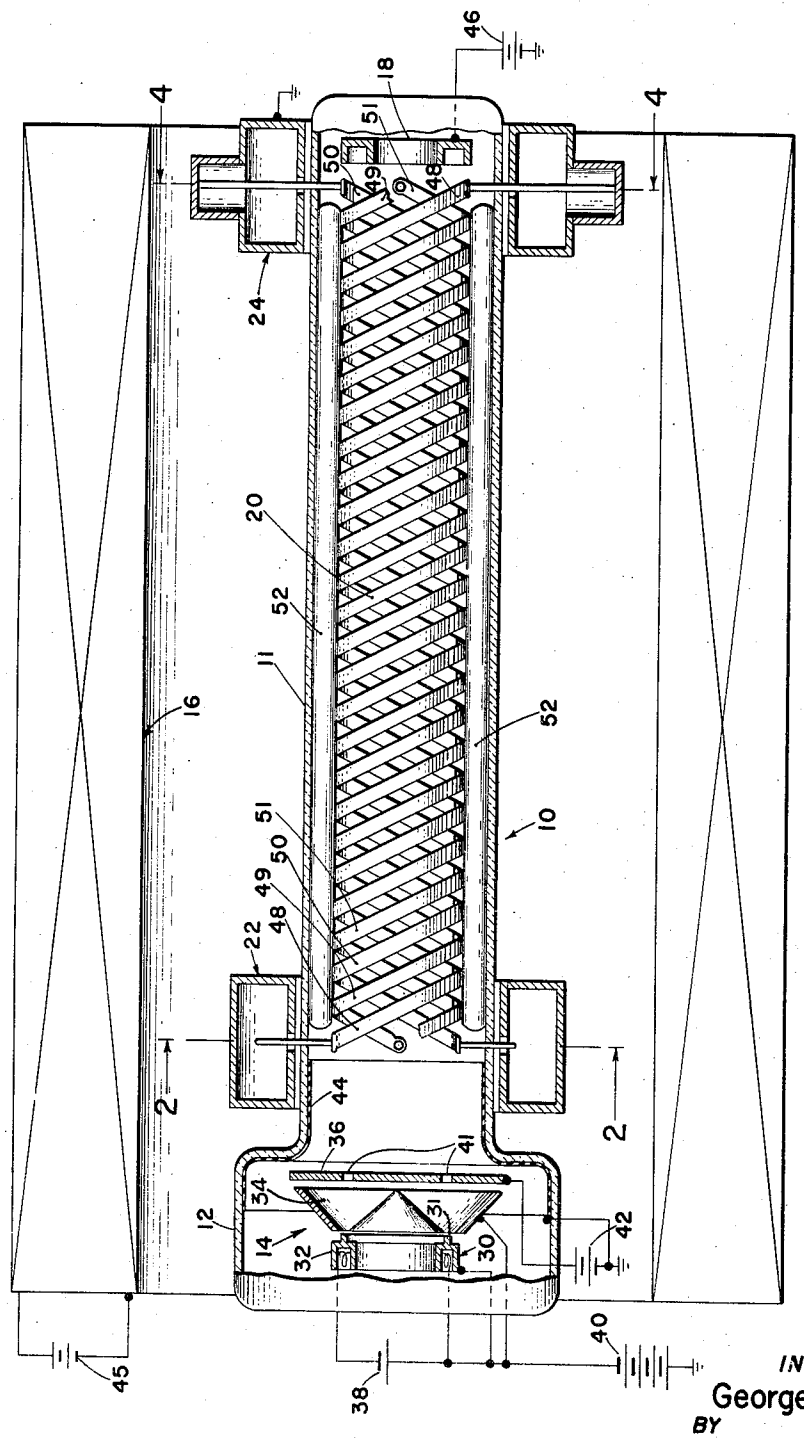



Fig. 1

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Fig. 3

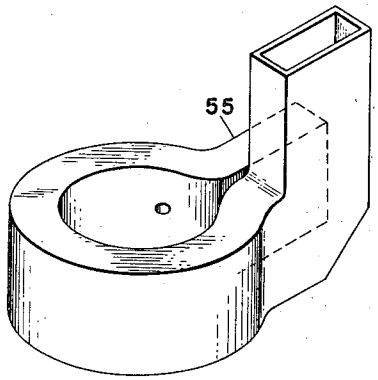



Fig. 2

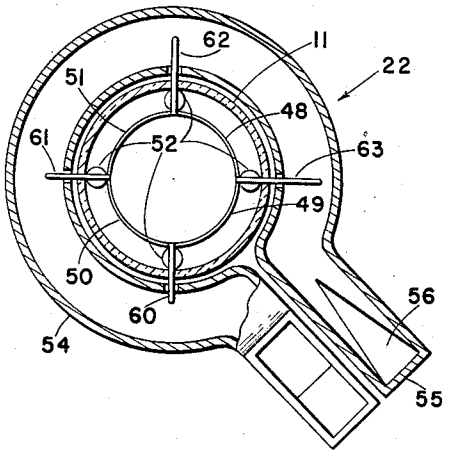



Fig. 4

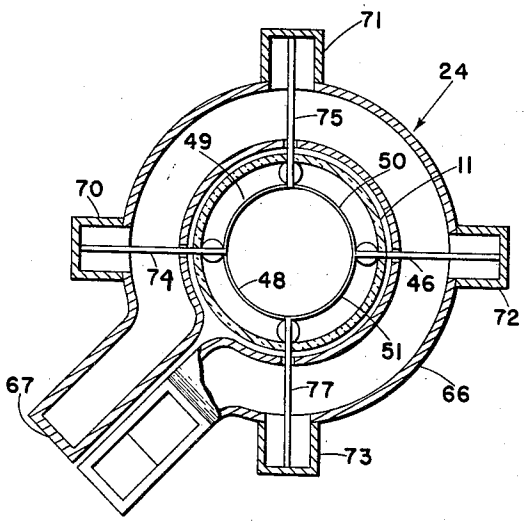
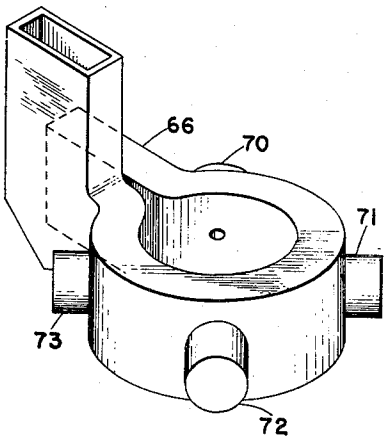



Fig. 5




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2,859,375

Patented Nov. 4, 1958



2,859,375

# MULTIFILAR HELIX COUPLING

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Application August 4, 1955, Serial No. 526,377

3 Claims. (Cl. 315—3.6)

This invention relates to traveling-wave tubes and more particularly to apparatus for transferring electromagnetic energy between a waveguide and a multifilar helix in a manner consistent with the use of the multifilar helix as the slow-wave structure in the traveling-wave tube.

Helices have found wide use in traveling-wave tubes wherein they are employed to propagate an electromagnetic wave along the path of an electron stream at a velocity to effect an energy transfer from the stream to the wave. The circumference of a helix, however, together with its concomitant cross-sectional area becomes increasingly smaller as progressively shorter wavelength signals are amplified. Thus, it is evident that as signals of increasingly higher frequencies are to be amplified, it is necessary to decrease the cross-sectional area of the electron stream in order for it to be accommodated by the helix. In order to overcome this limitation, it is the present practice to employ a multifilar helix which may have a circumference of the order of several wavelengths at the signal frequency in conjunction with a hollow electron stream. The use of a multifilar helix in this manner makes the circumference of the helix dependent upon the number of single helices constituting the multifilar helix. The use of a multifilar helix, however, presents the problem of coupling a single input source or output load to the several single helices of the multifilar helix.

In accordance with the present invention, an apparatus is provided for coupling between a waveguide and a multifilar helix, such that the helices are excited with $2\pi/N$ radians phase difference, where N is the number of single helices contained in the multifilar helix. This apparatus for coupling energy from a source to the multifilar helix comprises a section of rectangular waveguide which extends around the periphery of the tube envelope at an extremity of the helix and is then terminated in its characteristic impedance. A probe is extended radially outwards from the end of each single helix of the multifilar helix into the waveguide. The distance that each probe extends into the waveguide is adjusted so as to energize each single helix with approximately the same amount of energy. Further, the diameter of the waveguide about the tube envelope is chosen so that the intervening distance between adjacent probes within the waveguide is equal to $1/N$ guide wavelengths.

On the other hand, in the apparatus for transferring energy from the multifilar helix to the waveguide, the waveguide is not terminated so as not to dissipate one-half the energy of the output signal. Also, the probes may extend across the width of the waveguide to connect to the center conductor of shorted one-quarter wavelength coaxial stubs thereby enabling each helix of the multifilar helix to be maintained at the same potential as the waveguide. The spacing between the adjacent probes necessary to effect reinforcement of the energy transferred to the guide is $1/N$ guide wavelengths, as before.



It is therefore an object of this invention to provide an improved apparatus for coupling energy between a multifilar helix and a wave propagating structure.

Another object of the invention is to provide a traveling-wave tube incorporating a multifilar helix with improved apparatus for coupling electromagnetic energy to and from the helix.

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 drawings in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

Fig. 1 is a cross-sectional schematic diagram of an embodiment of the present invention together with associated circuitry;

Figs. 2 and 4 are views taken on sections 2—2 and 4—4 of Fig. 1, respectively; and

Figs. 3 and 5 are perspective views of the waveguide coupling sections of Figs. 2 and 4, respectively.

Referring now to Fig. 1 there is illustrated an embodiment of the present invention comprising an evacuated envelope 10 which includes an elongated portion 11 and an enlarged portion 12 at its left extremity, as viewed in the drawings. Housed within the enlarged portion 12 of envelope 10 is an electron gun 14 for producing a hollow cylindical electron stream. A solenoid 16 is disposed concentrically about the entire length of envelope 10 for directing the electron beam along a predetermined path through the elongated portion 11 thereof. A collector electrode 18 is disposed at the extremity of the path farthest from the electron gun 14 to intercept and collect the electron stream. Intermediate the electron gun 14 and the collector electrode 18, a multifilar helix 20 is disposed concentrically about the path of the electron stream. Input and output coupling sections 22 and 24 are disposed concentrically about the elongated portion 11 of envelope 10 opposite the extremities of the multifilar helix 20 for coupling electromagnetic energy to and from the helix 20, respectively.

More particularly, electron gun 14 comprises an annular cathode 30 with an electron emitting surface 31 and a heater 32, a focusing electrode 34, and an accelerating electrode 36. Heater 32 is connected across a battery 38, one terminal of which is referenced to the cathode 30. The focusing electrode 34 provides an inner and an outer surface of revolution commencing from the electron emitting surface 31 of cathode 30 and disposed at an angle of approximately 67.5 degrees with respect to the path of the electron stream. The focusing electrode 34 is maintained at the same potential as the cathode 30 by means of an appropriate connection thereto. In operation, the cathode 30 together with the focusing electrode 34 is maintained at a potential of the order of several thousand volts negative with respect to ground. This is accomplished by means of connections therefrom to the negative terminal of a battery 40, the positive terminal of which is referenced to ground. Accelerating electrode 36 is a disc-shaped electrode having a circular aperture 41 disposed in register with the electron emitting surface 31 of the cathode 30. The accelerating electrode 36 is maintained at a potential of the order of 200 volts positive with respect to ground by means of a connection therefrom to the positive terminal of a battery 42, the negative terminal of which is referenced to ground. An equipotential region is provided intermediate the electron gun 14 and the

commencement of the multifilar helix 20 by means of a conductive coating 44 disposed about the inner surface of the envelope 10 throughout this region. The potential of this equipotential region is maintained at ground by means of a connection from the coating 44 to ground.

The solenoid 16 is energized with a direct current provided by a battery 45 to produce an axial magnetic field along the longitudinal axis of the envelope 10 which serves to focus and constrain the electron stream along the predetedmined path to the collector electrode 18. This magnetic field may be of the order of from 600 to 1000 gauss. At the end of the path, the collector electrode 18 which intercepts and collects the electron stream is maintained at a potential of the order of 200 volts positive with respect to the potential predominating along the path so as to minimize secondary electron emission therefrom. This is effected by means of a connection from the collector electrode 18 to the positive terminal of a battery 46, the negative terminal of which is referenced to ground.

The multifilar helix 20 includes, for example, four tape-wound helices 48, 49, 50 and 51 which are fabricated from a metal such as molybdenum or tungsten. The principal prerequisites are that the helices 48–51 accurately retain their form with respect to pitch and diameter. The helices 48–51 are glazed to four ceramic rods 52 (see Fig. 2) which are disposed lengthwise along the helices in quadrature about the outer periphery thereof. The composite diameter of the helices 48–51 and the ceramic rods 52 is made equal to the inner diameter of the elongated portion 11 of envelope 10 so as to maintain the helices accurately in position with respect to the path of the electron stream.

Input coupling section 22 is disposed concentrically about the envelope 10 opposite the extremity of multifilar helix 20 nearest the electron gun 14. Referring to Fig. 2 the coupling section 22 comprises a length of rectangular waveguide 54 which is disposed in a toroidal manner about the elongated portion 11 of envelope 10, the width of the waveguide extending along the longitudinal axis of the tube. The waveguide 54 enters edgewise between the enlarged portion 12 of envelope 10 and the solenoid 16 and makes a single-miter H-plane bend towards the envelope 10, as shown in Fig. 3. Upon reaching the outer periphery of the envelope 10 the waveguide 54 makes a single-miter E-plane bend so as to continue around the envelope 10. After completing one revolution, the waveguide 54 makes a second single-miter E-plane bend in a direction radially outwards from the center line of the multifilar helix 20 whence it is terminated in its characteristic impedance to prevent reflections from this extremity. This termination is provided by means of a triangular resistive vane 56 disposed along the center of the waveguide in a manner such that it progressively increases in width as the end of the guide is approached. The end of the waveguide 54 is shorted by an end portion 55.

Commencing from the input end of the waveguide 54, probes 60, 61, 62 and 63 extend radially outwards from the helices 50, 51, 48, 49, respectively, into the toroidal chamber formed by the waveguide. The probes 60 to 63 extend from the respective helices by progressively increasing distances so as to couple substantially equal amounts of energy from the waveguide to each helix of the multifilar helix 20. The mean distance between each adjacent pair of probes is made equal to $1/N$ guide wavelengths at the operating frequency, wherein N is the number of helices comprising the multifilar helix 20. Thus, in the present case the mean distance between each adjacent pair of probes is one-quarter guide wavelength.

The waveguide output coupling section 24 is disposed about the envelope 10 opposite the extremity of multifilar helix 20 farthest from electron gun 14 in a manner similar to the waveguide coupling section 22. As indicated in Figs. 1 and 4, the waveguide coupling section 24 comprises a rectangular waveguide 66 which commences from an output end and proceeds edgewise between the solenoid 16 and the longitudinal portion 11 of envelope 10 to a point opposite the farthest extremity of multifilar helix 20 from the electron gun 14. At this point the waveguide 66 makes a single-miter H-plane bend inwards to the envelope 10 as shown in Fig. 5 and then another single-miter E-plane bend so as to proceed around the outer periphery of envelope 10. After making one complete revolution, the waveguide makes a second single-miter E-plane bend outwards and is terminated by a conducting end portion 67. Disposed opposite the extremity of the helices 48, 49, 50, 51 and commencing radially outwards from the outer wall of the waveguide 66 are shorted one-quarter wavelength coaxial stubs 70, 71, 72, and 73, respectively. Also, probes 74, 75, 76, and 77 extend radially outwards through the envelope 10 from the extremity of helices 48, 49, 50, 51 respectively, to connect to the center conductor of the stubs 70–73. The waveguide 66 is maintained at ground potential by means of a connection thereto. Thus, the helices 48–51 are also maintained at ground potential due to the connections therefrom to the waveguide 66 through the probes 74–77 and the center conductors of the shorted coaxial stubs 70–73. At the same time, a high virtual impedance is presented to the probes 74-77 in the plane passing through the inner surface of the outer wall of the waveguide 66 thus enabling the waveguide to be energized by an electric field. As before, the probes are spaced one-quarter guide wavelength apart as measured about the mean radius of the waveguide 66. In the case of the waveguide section 24, however, the waveguide 66 is not terminated in its characteristic impedance, as to do so would cause approximately one-half the output energy coupled from the multifilar helix 20 to be dissipated. Since the waveguide 66 is not terminated in its characteristic impedance, the shorted end portion 67 should be spaced an odd multiple of one-quarter guide wavelengths distance from the nearest probe 74. Also, in that the coupling section 24 is transferring energy from the multifilar helix to an output circuit it is desirable that a maximum amount of energy be transferred from each helix to the waveguide 66. Thus, it is evident that it is not necessary to have varying degrees of coupling between the helices 48–51 to the waveguide 66.

In its operation, the hollow cylindrical electron beam produced by electron gun 14 is directed along the predetermined path through the multifilar helix 20. The input of waveguide section 54 is energized with a signal wave to be amplified wherein it is coupled by the probes 60–63 to the helices 50, 51, 48, 49, respectively. Inasmuch as the adjacent probes are one-quarter guide wavelength apart, the energy coupled to successive probes is 90 degrees different in phase. The phase in a plane normal to the longitudinal axis of the multifilar helix 20 of each wave propagated by the helices 48–51 therefore differs by this same amount. Hence, it is evident that the phase of the waves propagated by the helices 48–51 presented to any elemental portion of the electron stream will be substantially the same. In this manner, longitudinal electric fields are formed which enable helices of substantially larger diameter to be employed. Similarly, the output coupling section 24, by employing the same spacing between the probes 74–77 as employed in the input coupling section 22, couples energy from the helices 48–51 that reinforces in the waveguide 66 to provide an amplified output signal.

What is claimed is:

1. A transition apparatus for coupling electromagnetic energy between an N-filar helix and a waveguiding structure, said transition apparatus comprising an N-filar helix wherein N is an integer no less than two and the

N helices constituting said N-filar helix are terminated in a common plane normal to the longitudinal axis thereof, N probes extending radially outwards from the respective terminations of each of said N helices constituting said N-filar helix, and a length of waveguide coupled to spaced intervals therealong to respective ones of said N probes and being wound circularly substantially about said helix parallel to said common plane for propagating an electromagnetic wave having a transverse electric field along a path orthogonal to and through a region containing said N probes, the phase difference of said wave along said path between successive probes being $2\pi/N$ radians.

2. The apparatus as defined in claim 1 wherein said length of waveguide for propagating said wave comprises a rectangular waveguide disposed with its broad side parallel to the longitudinal axis of said N-filar helix.

3. A traveling-wave tube comprising an electron gun for producing a hollow cylindrical electron stream, means for directing said electron stream along a predetermined path, an N-filar helix where N is an integer no less than two, disposed concentrically about and adjacent to said predetermined path, the N-helices forming said N-filar helix being terminated in two common planes normal to the longitudinal axis of said N-filar helix at both extremities thereof, apparatus coupled to a source providing an electromagnetic signal wave for launching said wave along said N-filar helix in the direction of electron flow, said apparatus comprising a rectangular waveguide disposed concentrically about the extremity of said N-filar helix first entered by said electron stream, the broad side of said waveguide being parallel to the longitudinal axis of said helix, and N probes extending radially outwards from the extremity of each of said respective N helices and entering progressively increasing distances into said waveguide commencing with the probe nearest the input thereto, thereby to couple substantially equal amounts of energy to each of said helices, the distance between adjacent probes along said waveguide being equal to $2\pi/N$ radians at the frequency of said wave




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