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K. R. EVANS ETAL

3,239,713

HIGH FREQUENCY MODE TRANSFORMATION BETWEEN BALANCED TRANSMISSION
LINE AND WAVEGUIDE, USEFUL IN TRAVELLING WAVE TUBES

Filed March 25, 1963

2 Sheets-Sheet 1

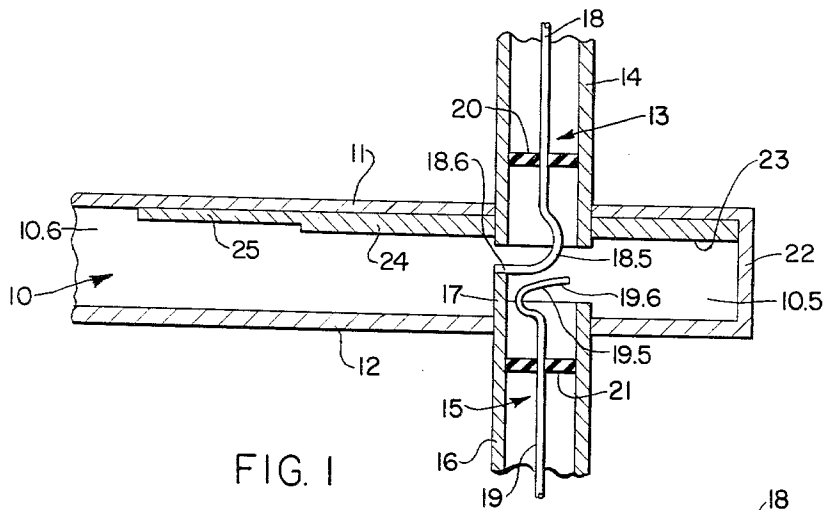


FIG. 1

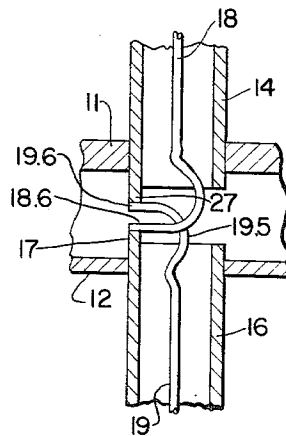


FIG. 1A

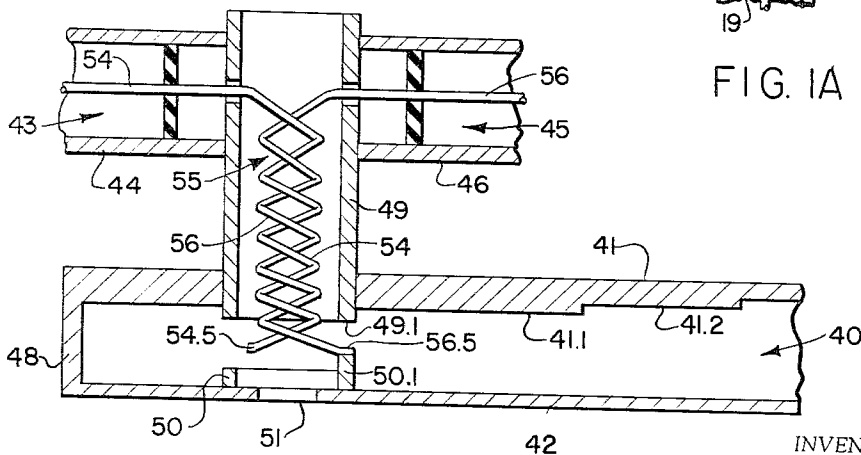


FIG. 2

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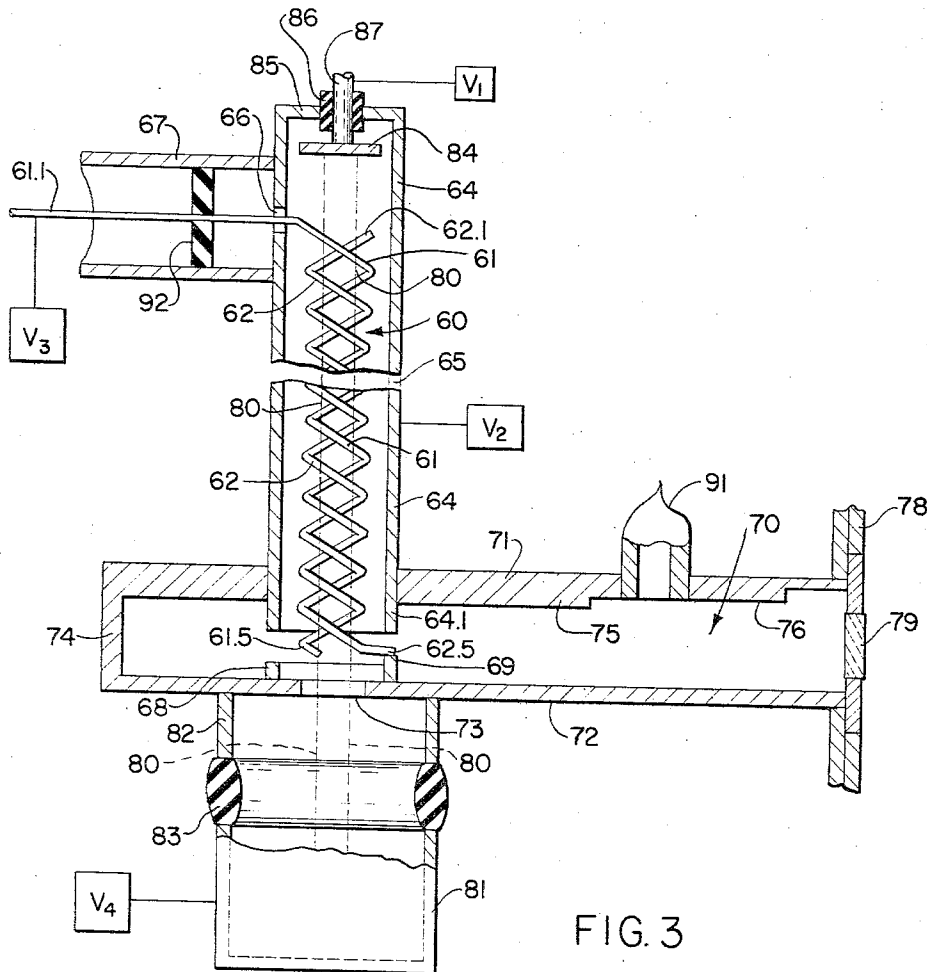


FIG. 3

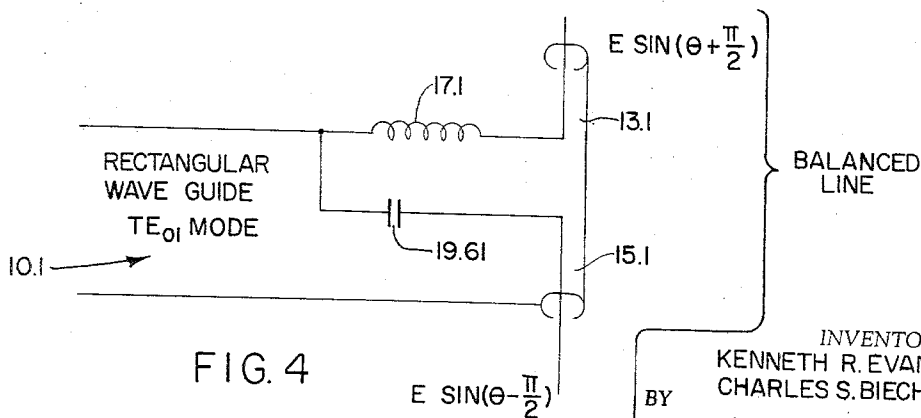


FIG. 4

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7 Claims. (Cl. 315—3.5)

This invention relates in general to high frequency mode transformers for electromagnetic wave energy, and more particularly to such transformers useful at so-called microwave frequencies to transform a signal directly between a balanced mode in a transmission line and a mode suitable for propagation in a waveguide or an unbalanced line.

The problem of coupling energy from a balanced transmission line to an unbalanced transmission line or to a waveguide, that is, to transform between a balanced mode and an unbalanced or waveguide mode, has up to now required the use of magic T's, baluns or the like, which are bulky and complex. Thus, for example, in a traveling wave electron tube of the backward wave oscillator (BWO) type employing a bifilar helix as the slow-wave transmission line, in order to couple the output only to the first backward mode of the bifilar helix, up to now it has been the practice to connect the respective helices separately to the center conductor of separate coaxial transmission lines placed 180° apart electrically. This has resulted in two separate outputs from the tube which are 180° out of time phase forming a balanced line, and presenting the aforementioned requirements to combine them into a single output.

It is the principal object of the present invention to provide a simple and compact transformer for combining the two oppositely-phased components of a balanced-mode signal directly into a single unbalanced- or waveguide-mode signal without requiring the use of the usual balun, magic T or the like. According to a specific embodiment of the invention as applied to a BWO employing a bifilar helix as the slow-wave transmission line, this object is realized by transforming a backward-wave operating in the balanced mode on the bifilar helix slow-wave structure to the TE₁₀ mode in rectangular waveguide, thereby providing a single-ended waveguide output directly from the slow-wave structure. More generally, the same technique will provide a microwave transformer which transforms a microwave signal from a balanced line directly to an unbalanced line or a waveguide, or from a waveguide or an unbalanced line directly to a balanced line. This mode transformer is a reciprocal device, and may be used to transform any balanced two-wire line to a waveguide, and vice versa, for example.

In its broader aspects, the invention contemplates apparatus for transforming a high frequency signal between a balanced mode in a first transmission line and a different mode in a second transmission line comprising first transmission line means adapted to propagate said signal in a balanced mode, second transmission line means adapted to propagate said signal in the different mode, transducer means associated with said second transmission line means to couple with said signal in said different mode, and means coupling said first transmission line means with said transducer means.

In one of its more specific aspects, the invention contemplates apparatus for transforming a high frequency signal between a balanced mode in a transmission line and the TE₁₀ mode in rectangular waveguide comprising transmission line means adapted to propagate said signal in a balanced mode, a rectangular waveguide adapted to propagate said signal in the TE₁₀ mode, transducer means associated with said waveguide to couple with the TE₁₀

mode therein, and means coupling said transmission line means with said transducer means.

The invention will be described below with particular reference to its utility in traveling wave electron tubes. In this aspect, the invention contemplates a traveling wave electron tube for high frequency signals, a slow-wave transmission line adapted to propagate a high frequency signal in a balanced mode, waveguide means adapted to propagate said signal in a desired waveguide mode, transducer means associated with said waveguide means to couple with said signal in said desired mode, and means coupling said transmission line means with said transducer means.

The invention will now be described with reference to the accompanying drawings, wherein:

FIG. 1 is a longitudinal section through a first embodiment;

FIG. 1A is a partial longitudinal section showing a modification of FIG. 1;

FIG. 2 is a longitudinal section through a second embodiment;

FIG. 3 is a longitudinal section through a BWO employing the invention; and

FIG. 4 is a simplified equivalent circuit of FIG. 1.

Referring to FIG. 1, a rectangular waveguide 10 has top and bottom wide walls 11 and 12, respectively. A first coaxial line 13 has its outer conductor 14 connected through the top wall 11, and a second coaxial line 15 has its outer conductor 16 connected through the bottom wall 12. The coaxial lines are collinear, and the inner end of the second coaxial line 15 has an antenna element 17 mounted on it projecting across the waveguide 10 toward but not touching the inner end of the first coaxial line 13. The first inner conductor 18 is formed into a loop 18.5 as it enters the waveguide from the first coaxial line 13, and its inner end 18.6 is connected directly to the antenna element 17. The second inner conductor 19 is formed into a loop 19.5 as it enters the waveguide from the second coaxial line 15, and its inner end 19.6 is free, being oriented generally along the axis of the waveguide 10. Insulators 20, 21 may be used to support the respective inner conductors 18 and 19 in the first and second coaxial lines 13 and 15, respectively.

The waveguide 10 has a transverse wall 22 across one end 10.5, and is provided with thickening slabs 23, 24, 25 inside the top wide wall 11, as impedance transformer means. These slabs can be integral with the wall 11, if desired. The open (left hand in FIG. 1) end 10.6 of the waveguide 10 will in practice be coupled to a connecting circuit or circuits (not shown).

In the simplified equivalent circuit of FIG. 4, the coaxial lines 13 and 15 of FIG. 1 are represented by the balanced line comprised of parts 13.1 and 15.1, the antenna element 17 by an inductive coupling 17.1 to one side of the waveguide 10.1, and the free end 19.6 of the second inner conductor by a capacitive coupling 19.6.1. Referring again to FIG. 1, it will be appreciated that the antenna element 17, projecting across the waveguide 10 between the wide walls 11 and 12, is parallel to the electric vector of the TE₁₀ mode, and is therefore correctly oriented to couple with that mode in the waveguide. The antenna element 17 can be located on the guide axis, or to one side of it, as desired; as shown in FIG. 1 it is substantially in the guide axis.

Referring to FIG. 1A, both inner conductors 18 and 19 may be connected to respective individual antenna elements 17 and 27. In this case the end 19.6 of the second inner conductor is connected to the second antenna element 27, which is mounted on the inner end of the first outer conductor 14 and projects toward but does not touch the first antenna element 17. Preferably the two antenna elements 17 and 27 are in the same transverse plane in

the waveguide 10, and signals impressed on their confronting ends from the lines 13 and 15 operating in a balanced mode will readily launch the TE_{10} mode in the guide, and vice versa.

Referring now to FIG. 2, a waveguide 40 has top and bottom wide walls 41 and 42, respectively, and a transverse wall 48 closing one end. A tubular section 49 is mounted to the waveguide through the top wide wall 41, and the inner end 49.1 projects a distance into the guide. Confronting the inner end 49.1 is a similar second tubular section 50 mounted on the inner surface of the bottom wide wall 42. An antenna element 50.1 is mounted to the second tubular section 50 and projects toward but does not touch the inner end 49.1 of the first tubular section 49.

First and second coaxial lines 43 and 45 are coupled to opposite sides of the first tubular section 49 near the end thereof remote from the waveguide 40. The outer coaxial conductors 44 and 46 are connected directly to the outer walls of the tubular section 49. The respective inner conductors 54 and 56 pass through apertures 43.5 and 45.5, respectively, in the walls of the tubular section 49, and then form a bifilar helix 55 within the same tubular section. The end 56.5 of the second inner conductor which extends into the waveguide 40 is connected directly to the antenna element 50.1. The end 54.5 of the first inner conductor 54 which extends into the waveguide is free, being oriented generally along the axis of the guide. An aperture 51 may be provided in the bottom wall 42 of the waveguide, through which an electron beam (not shown) may be projected to cooperate with the bifilar helix 55. Many useful arrangements are possible, and one is described below in connection with FIG. 3.

In FIG. 2, impedance matching structural members 41.1 and 41.2 are integral with the top wall 41. In all of the embodiments illustrated, the closed end of the waveguide functions as a tuning stub for the desired waveguide mode, according to known techniques. That is, the transverse wall, 22 in FIG. 1, or 48 in FIG. 2, is so located relative to the effective transverse plane of transformation from the balanced mode to the unbalanced mode as to reinforce the unbalanced mode in the waveguide.

The BWO shown in FIG. 3 employs a bifilar helix 60 as a slow-wave transmission line. The helix is made of two conductors 61 and 62, and it is located in an electrically-conductive tube 64, being supported therein by any suitable known means (not shown), of which many are known to the art. The tube and wires are shown broken apart at 65 to indicate that in practice the helix 60 will usually be physically longer than is indicated in the illustration; the latter is not drawn to any particular scale.

The tube 64 is mounted through the top wall 71 of a waveguide 70, with its end 64.1 projecting into the waveguide.

A tubular section 68 is mounted on the inner surface of the bottom wide wall 72 of the waveguide, collinearly confronting and spaced from the tube 64. An antenna element 69 is mounted on the tubular section extending toward but not touching the inner tube end 64.1. The end 62.5 of one of the helix wires 62 inside the guide is connected directly to the antenna element 69. The end 61.5 of the other helix wire 61 inside the guide is free, being oriented generally along the guide axis. The other end 61.1 of the latter helix wire 61 is brought out of the tube 64 through an aperture 66 surrounded by an outer coaxial conductor 67 which is connected directly to the wall of the tube 64. The other end 62.1 of the former helix wire is terminated free within the tube 64.

An aperture 73 is provided in the bottom wide wall 72, opening into the region surrounded by the tubular section 68 and giving access to the axial region of the helix for an electron beam represented by dashed lines 80 from an electron gun structure which is represented by a housing

81 of electrically conductive material. The housing 81 is mounted to the outer surface of the bottom wide wall 72 by means of an electrically conductive ring 82 surrounding the aperture 73 and an intervening insulating ring 83. A collector electrode 84 is mounted through the remote end wall 85 of the tube 64, being insulated therefrom by means of an insulator 86 in which a supporting conductor 87 for the collector electrode is in turn supported.

The waveguide 70 has a transverse wall termination 74 at the left-hand end (in FIG. 3), and impedance transformer elements 75, 76 integral with its top wall 71. The other end 77 of the waveguide is the output end, and will in practice usually be fitted with means, such as a coupling flange 78, for coupling to a circuit using the BWO. To allow the tube to be exhausted, the flange may be fitted with a waveguide window 79 of any desired form, and exhaust means such as a sealable tubulation 91 may be provided through a wall of the waveguide. An insulating support 92 for the helix conductor 61 in the outer coaxial conductor 67 also represents a seal at this part of the BWO.

Traveling wave tubes employing a bifilar helix as the slow-wave transmission line are known. We may employ a solid or a hollow electron beam 80; we provide a potential difference between the wires 61 and 62 of the helix 60 such that the beam will be periodically electrostatically focused. It will be observed that, for D.C., the helix conductor 62 which is connected to the antenna 69 is at the same potential V_2 as the tube 64; generally speaking V_2 will be ground potential. Thus, by applying a different potential V_3 to the other helix conductor 61 at the outer end 61.1 thereof, a potential difference can be established between the helix turns for beam focusing purposes. V_1 and V_4 represent suitable collector and electron gun potentials, respectively.

With the structure of FIG. 3 the first backward wave mode propagating along the bifilar helix 60 is directly transformed to the TE_{10} mode in the rectangular waveguide 70. The antenna structure may be modified according to FIG. 1A, if desired, but in that case it will be desirable to insulate the tube 64 from the waveguide 70 or take other suitable steps in order to retain the ability to maintain a D.C. potential difference between the helix conductors 61 and 62.

The embodiments of the invention which have been illustrated and described herein are but a few illustrations of the invention. Other embodiments and modifications will occur to those skilled in the art. No attempt has been made to illustrate all possible embodiments of the invention, but rather only to illustrate its principles and the best manner presently known to practice it. Therefore, while certain specific embodiments have been described as illustrative of the invention, such other forms as would occur to one skilled in this art on a reading of the foregoing specification are also within the spirit and scope of the invention, and it is intended that this invention include all modifications and equivalents which fall within the scope of the appended claims.

What is claimed is:

1. Apparatus for transforming a high frequency signal between a balanced mode in a transmission line and a desired mode in a waveguide comprising: transmission line means having at least a first conductor and a second conductor adapted to propagate said signal in a balanced mode, waveguide means adapted to propagate said signal in said desired mode, antenna means in said waveguide means extending from an inner wall to the axial region thereof and oriented to couple with said signal in said desired mode, said first conductor and said second conductor each terminating within said waveguide substantially in said region, and means directly connecting said first conductor with said antenna means in said axial region, said second conductor terminating in said axial region spaced from and making no physical or electrical contact with said waveguide means.

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2. Apparatus for transforming a high frequency signal between a balanced mode in a transmission line and a desired mode in a waveguide comprising: transmission line means including two conductors forming a bifilar helix adapted to propagate said signal in a balanced mode, waveguide means adapted to propagate said signal in said desired mode, an antenna in said waveguide means extending from an inner wall thereof to the axial region thereof and oriented to couple with said signal in said desired mode, and means directly connecting only one of said conductors to said antenna in said axial region, the other of said conductors terminating in said axial region spaced from and making no physical or electrical contact with said waveguide means.

3. Apparatus for transforming a high frequency signal between a balanced mode in a transmission line and the TE_{10} mode in a rectangular waveguide comprising: transmission line means including two conductors forming a bifilar helix adapted to propagate said signal in a balanced mode, a rectangular waveguide adapted to propagate said signal in the TE_{10} mode, an antenna in said waveguide extending from one wide wall thereof to the axial region thereof and oriented to couple with the TE_{10} mode, and means directly connecting only one of said conductors to said antenna in said axial region, the other of said conductors terminating in said axial region spaced from and making no physical or electrical contact with said waveguide.

4. In a traveling wave electron tube for high frequency signals, a two-conductor bifilar helix slow-wave transmission line adapted to propagate a high frequency signal in a balanced mode, a rectangular waveguide adapted to propagate said signals in the TE_{10} mode, an antenna in said waveguide oriented to couple with the TE_{10} mode, one only of the conductors of said helix being connected at one end thereof directly to said antenna, the other of said conductors terminating substantially on the axis of said waveguide and making no physical or electrical contact with said waveguide.

5. In a traveling wave electron tube for high frequency signals, a two-conductor bifilar helix slow-wave transmission line adapted to propagate a high frequency signal in a balanced mode, a hollow rectangular waveguide having electrically conductive walls and adapted to propagate said signal in the TE_{10} mode located adjacent one end of said helix, an antenna in said waveguide oriented to couple with the TE_{10} mode, one only of the conductors of said helix at said one end being connected directly to said antenna, electron beam means to propagate a stream of electrons from said one end to the other end of said helix in energy-exchanging relation with a signal therein, and means connected between said waveguide and the other of said conductors to apply a beam-focusing potential difference between the conductors of said helix.

6. In an electrical structure, a two-conductor bifilar helix transmission line adapted to propagate a signal in a balanced mode, a hollow electrical conductor surrounding said helix and spaced therefrom, a hollow rectangular waveguide adapted to propagate said signal in the TE_{10}

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mode and having electrically conductive walls and an opening in one wall for receiving one end of said hollow conductor therethrough, said waveguide and hollow conductor being electrically and mechanically connected together at said wall, an end of said helix extending into the axial region of said waveguide through said end of said hollow conductor, an antenna in said waveguide connected at one end to one wall thereof and oriented to couple with the TE_{10} mode in said waveguide, said antenna terminating at its other end in said axial region, the end of one of said conductors at said end of said helix being connected directly to said antenna, the end of the other of said conductors at said end of said helix being disposed in said axial region and making no direct electrical contact with said waveguide.

7. In a traveling wave electron tube, a two-conductor bifilar helix slow-wave transmission line adapted to propagate a signal in a balanced mode, a hollow electrical conductor surrounding said helix and spaced therefrom, a hollow rectangular waveguide adapted to propagate said signal in the TE_{10} mode and having electrically conductive walls and an opening in one wall for receiving one end of said hollow conductor therethrough, said waveguide and hollow conductor being electrically and mechanically connected together at said wall, one end of said helix extending into the axial region of said waveguide through said end of said hollow conductor, an antenna in said waveguide connected at one end to one wall thereof and oriented to couple with the TE_{10} mode in said waveguide, said antenna terminating at its other end in said axial region, the end of one of said conductors at said one end of said helix being connected directly to said antenna, the end of the other of said conductors at said one end of said helix being disposed in said axial region and making no direct electrical contact with said waveguide, electron beam means to propagate a stream of electrons from said one end to the other end of said helix in energy-exchanging relation with a signal therein, and means coupled between said waveguide and said other of said conductors to apply a beam-focusing potential difference between the conductors of said helix.

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