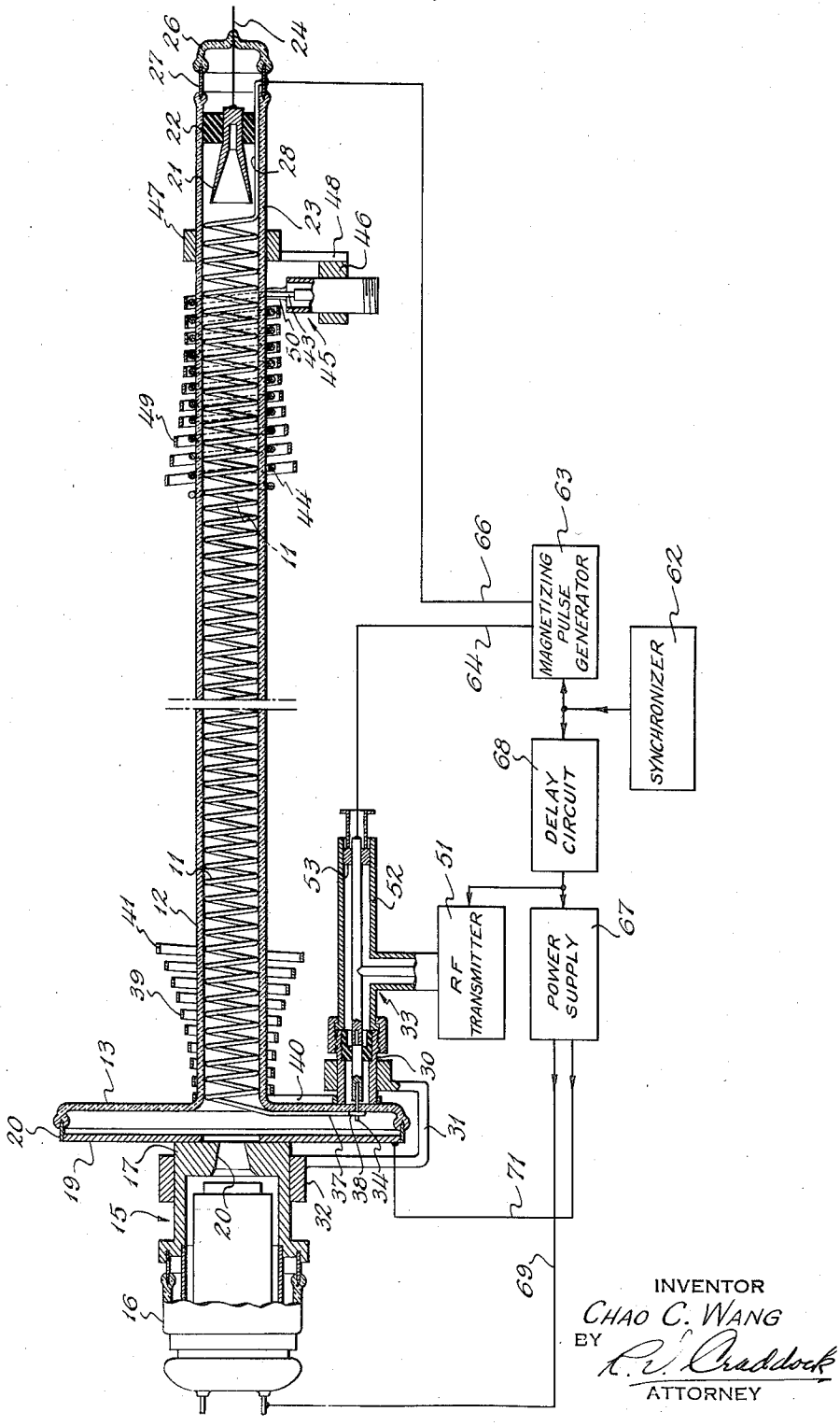
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TRAVELLING WAVE TUBE

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TRAVELLING WAVE TUBE

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The present invention relates to travelling wave tubes and particularly apparatus for enhancing the transfer of microwave energy between the helix of such a tube and external microwave transmission line devices.

A typical example of helix to transmission line transition apparatus for a travelling wave tube comprises a tapered tubular horn section surrounding the helix along one end region thereof with an end of a coaxial transmission line inner conductor being connected to the helix wire and the coaxial line outer conductor being connected to the smallest end of the horn. The horn is tapered in a certain manner for providing an impedance match and mode conversion between coaxial line and helix microwave energy.

Although apparatus as aforedescribed can be made for operation over a relatively broad band of frequencies, it can be appreciated that once the taper design and length of the horn section is chosen, it would be difficult to change the transition characteristics thereof. A change may be desirable, for example, wherein it is required to provide an optimum transition at a particular frequency or for further improving operation over a particular frequency band after the tube has been constructed. Furthermore, if the travelling wave tube is of the pulsed beam type whose beam configuration is preserved by a pulsed axial magnetic beam controlling field established along the beam axis in synchronism with the beam pulses, a horn section as aforedescribed could not be employed since it would comprise a shorted turn tightly coupled and linked with the pulsed axial magnetic field. Such a shorted turn acts like a short-circuited secondary of a transformed by virtue of currents induced therein by the pulsed magnetic field, thereby considerably reducing the effectiveness of the axial magnetic beam controlling field.

Therefore, it is an object of the present invention to provide a travelling wave tube having a helix to transmission line transition section whose characteristics can be readily changed for optimizing reflectionless energy transfer between transmission line and helix microwave energy.

It is a further object of the present invention to provide a travelling wave tube having an improved helix to transmission line transition section for microwave energy which is readily employed even though a pulsed magnetic field is used for beam focusing.

The foregoing and other objects and advantages of the present invention are attained in a travelling wave tube wherein part of an impedance matching and mode converting transition section between the travelling wave helix and an external microwave transmission line comprises a spiral conductor of tapered diameter surrounding an end portion of the travelling wave helix. One conductor of a dual conductor transmission line is connected to the end of the spiral conductor of smaller diameter, the other conductor of the transmission line being coupled to the travelling wave helix. The aforementioned other conductor is coupled by a direct connection

to the helix or by means of a further helical conductor connected to said other conductor and coaxially supported between the travelling wave helix and the spiral conductor for mutual coupling of microwave energy from the helix to the further helical conductor. The present invention and advantages thereof may be better understood from the accompanying specification and drawings wherein.

The sole figure of the drawings comprises a partial sectional view of the travelling wave tube together with a schematic block diagram of means for pulsing the electron beam and means for establishing a pulsed magnetic beam controlling field along the axis of the travelling wave tube helix.

Referring to the drawings, a travelling wave helix conductor **11** is shown coaxially supported within a glass dielectric tubular envelope **12** having a flanged end portion **13**. An electron gun assembly **15** is provided at the flanged end **13** of the envelope **12** for producing and directing an electron beam for passage through an apertured accelerator electrode **17** into the helix **11**. An annular metallic plate member **19** brazed to accelerator electrode **17** and a "Kovar" metal vacuum sealing ring **20** brazed to the periphery of member **19** and vacuum sealed to an edge of the glass flange **13** support the gun **15** in coaxial relationship with the helix **11**. The electron gun is vacuum sealed at its lower end by a conventional glass bulb **16** vacuum sealed to a tubular extension from the accelerator electrode **17**.

The electron gun is of the type disclosed in U. S. Patent 2,707,758, published May 3, 1955, in the name of the present inventor, for example. Such a gun produces a high current density electron beam which is convergent from the gun cathode to a predetermined point within the aperture **20** of accelerator electrode **17**. The accelerator electrode **17** and the tubular extension therefrom is of highly permeable magnetic material, for example, and comprises a magnetic pole piece forming part of magnetic means for establishing an axial magnetic field for preserving the configuration of the electron beam beyond electrode **17** so that it has a constant diameter along helix **11**. The aforementioned point of minimum beam diameter corresponds to the effective plane of entrance into the magnetic field, the field causing the beam electrons to travel along helical paths of constant radii through the helix **11**. The diameter of the beam along helix **11** should be slightly less than the inner diameter of the helix, the beam velocity being regulated by proper choice of the accelerating voltage between the accelerator electrode **17** and cathode of gun assembly **15** to be slightly larger than the axial velocity of a travelling electromagnetic wave along helix **11** in accordance with principles known in the art for travelling wave amplification.

A collector electrode **21** is coaxially supported within the glass envelope **12** at the other end of helix **11** by means of a dielectric spacer element **22**. A lead **24** having an end soldered to collector **21** extends in vacuum sealed relationship through a glass end cap **26** for the tube, the end cap **26** being sealed in vacuum relationship with the glass tube **12** by means of a cylindrical metallic "Kovar" ring member **27**. An end portion **28** of the wire forming helix **11** extends through an aperture in spacer element **22** and is soldered to the ring member **27**. Thus, the helix **11** and collector **21** are insulated from each other and readily connected to different external leads.

A coaxial line connector **30** at the input end of the tube is supported by a bracket **31** joined to a ring **32** affixed to the electron gun assembly **15**. Connector **30** is provided for coupling to an input coaxial line **33** for supplying input microwave energy to the travelling wave tube. A "Kovar" wire **34** is soft soldered to an end of

the inner conductor of the connector 30 and passes through the glass flange 13 in vacuumed sealed relationship therewith. An end portion 37 of the conductor forming helix 11 extends from the first helix turn at the input end of the tube and is brazed to a metallic eyelet 38 spot welded to the wire 34. Thus, it can be seen that the input end of helix 11 is connected by a continuous conductive path to the inner conductor of coaxial line 33 for receiving energy therefrom.

A continuous spiral tape conductor 39 is positioned about the glass envelope 12 and the helix 11 in concentric relationship therewith as shown in the drawings, an end portion 40 of conductor 39 extending from the first turn of conductor 39 in parallel adjacent relationship with conductor 37 for connection to the outer conductor of connector 30. The end of conductor 40 is looped around and brazed to the end of the outer conductor of connector 30, conductor 39 being sufficiently rigid so as to require no further means of support along helix 11.

The adjacent conductor portions 37 and 40 connected to the inner and outer conductors of the coaxial line connector 30, respectively, form a dual conductor transmission line. The spacing between conductor portions 37 and 40 is chosen (taking into account that there is a glass dielectric therebetween) so that the impedance between conductors 37 and 40 is substantially the same as that of the coaxial line receptacle 30 and coaxial line 33. The conductor 39 is shown in the form of a tape, although it should be apparent that it could comprise a wire if desired. Also it makes no appreciable difference whether or not the conductor forming helix 11 is in the form of a tape or wire.

The turns of spiral conductor 39 extend along an end region of helix 11 and have an increasing diameter proceeding further along helix 11 towards the output end of the tube. The conductor 39 may be made to be somewhat flexible so that the spacings between turns and the radii of the turns thereof can be adjusted for enhancing the efficiency of the transition. The adjacent turns of conductor 39 are spaced from each other so as not to be shorted, the transverse end 41 of conductor 39 being free and unshorted.

Generally, there is approximately a one to one ratio between the turns of helix 11 and the turns of spiral conductor 39, the impedance therebetween at the first turns of conductor 39 and helix 11 increasing from an impedance corresponding to that of the aforementioned dual conductor transmission line 37, 40 to approximately that of the impedance of the helix 11 alone at microwave frequencies of operation. The spiral conductor 39 extends axially along helix 11 with the axial extent of conductor 39 and the exact spacings between turns of the spiral conductor and radii thereof being best determined empirically.

An output coaxial transmission line connector 45 similar to connector 30 is supported in fixed relationship relative to the tube envelope 12 at the output end of helix 11. This is effected by means of rings 46 and 47 affixed to connector 45 and the glass envelope 12, respectively, and a bracket 48 affixed between rings 46 and 47. The connector 45 has its inner conductor connected by means of conductor lead 43 to an end of a constant diameter helical conductor section 44 disposed along a portion of helix 11 in concentric relationship therewith, conductor 44 being supported upon the external wall of the tube envelope 12 along a region about helix 11.

The helical conductor section 44 is wound oppositely from the helix 11 and is made to have nearly the same phase velocity as helix 11, i. e., helices 11 and 44 considered without being in the presence of each other should have substantially the same phase velocities. The adjacent turns of conductor 44 are spaced from each other so as not to be shorted, the transverse end of conductor 44 farthest from the collector 21 being free and unshorted.

The desired length of helical conductor 44 for optimum transfer of energy from helix 11 to conductor 44 is best determined empirically. Preferably, helical conductor 44, which is separated from helix 11 by the glass dielectric envelope 12, should have a length at the center operating frequency for the device which results in maximum coupling of energy from helix 11 to helical conductor 44 without transferring any appreciable energy back to helix 11. The desired length may be determined theoretically in accordance with the article entitled "Coupled Helices," found in The Bell System Technical Journal, volume XXXV, Number 1, January 1956.

The outer conductor of the output transmission line connector 45 is connected to a spiral tape conductor 49 similar to spiral conductor 38 except conductor 49 is preferably wound in the same direction as conductor 44 and generally follows the turns thereof as shown in the drawings. An end portion 50 of conductor 49 extends downward from conductor 49 in parallel relationship with the conductor lead 43 and is brazed to the outer conductor of coaxial line connector 45 for providing the aforementioned connection. The adjacent turns of conductor 49 are spaced from each other so as not to be shorted, the transverse end farthest from connector 45 being free and unshorted.

The radii of the turns of spiral conductor 49 are tapered as illustrated for providing an impedance and mode conversion for energy transferred from helix 11 to the helical conductor 44 to be supplied to the coaxial line connector 45 by the section of dual conductor transmission line formed by conductive members 43 and 50. The impedance between members 43 and 50 as a transmission line approximates that of the connector 45, the impedance between the turns of conductors 44 and 49 increasing from that of the aforementioned transmission line to the impedance of helical conductor 44 alone proceeding toward an intermediate region of the tube. If desired, dielectric spacer elements might be provided between the spiral conductor 49 and helical conductor 44 to prevent one from being shorted to the other at the smaller end of conductor 49.

An R. F. transmitter of microwave energy 51 is connected to the input coaxial line 33 for supplying microwave energy over a predetermined operating frequency range to the helix conductor 11 for interaction with the electron beam projected along the helix. A right angle bend is provided along coaxial line 33, a quarter wavelength stub 52 being connected thereto as shown for optimizing energy transfer around the bend. An adjustable metallic piston 53 shorting the inner and outer conductors of stub line 52 is provided for enhancing energy transfer around the right angle bend in conductor 33. It should be apparent that any broad band stub known in the art could be substituted for the stub 52 wherein broad band operation without adjusting the shorting piston of the stub is desired.

In operation, assuming that the configuration of the electron beam along the helix 11 is maintained at a substantially constant diameter by a suitable magnetic focusing system such as that described further on below, microwave energy at a frequency of several thousand megacycles, for example, is produced by the transmitter 51 and delivered to the travelling wave helix 11 via coaxial line 33, and coaxial line receptacle 30 and the dual conductor transmission line comprising conductor portions 37, 40. The first turn of spiral conductor 39 connected to a conductor 40 overlaps the first turn of the helix 11 connected to conductor 37 with the spacing therebetween being such that the aforesaid turns also comprise a dual conductor transmission having approximately the same characteristic impedance as the transmission line formed by conductor portions 37, 40. The diameter of the spiral conductor 39 is gradually increased so that the impedance between conductor 39 and helix 11 as a dual-conductor transmission line increases proceeding along the tube towards the intermediate portion

of helix 11. The impedance of the aforementioned transmission line and coaxial line 33 might be in the neighborhood of 50 ohms, for example, the impedance of helix 11 being appreciably higher for operating frequencies in the neighborhood of several thousand megacycles, for example. Since the turns of spiral conductor 39 are spaced further and further from the helix 11, the impedance gradually changes to that of the helix 11 alone. Furthermore, the electric lines of force initially between the turns of spiral conductor 39 and the turns helix 11 gradually become modified so as to substantially exist only between the turns of helix 11 alone at the larger end of spiral conductor 39, whereby the microwave energy is propagated in the helix mode along the helix 11.

If the conductor 39 is flexible, the spacings between the turns and the radii of the turns thereof can be adjusted by the operator of the tube for optimum transfer of energy at any particular frequency or over a particular frequency band. Generally, the spiral conductor 39 extends axially of the helix for at least one wavelength for helix energy at the lowest operating frequency, the larger end of conductor 39 being just outside the effective radial extent of the electric field for the helix mode of operation at such a frequency.

As the helix travelling wave energy proceeds along the helix 11 towards the output end thereof, it interacts with the electron beam (whose velocity is slightly greater than the axial velocity of the helix travelling wave) so as to become amplified in a manner typical for travelling wave tubes. The energy along helix 11 is transferred by mutual coupling to the helical conductor 44 at the output end thereof, the spiral conductor 49 causing this energy to be gradually converted into a dual-conductor transmission line mode of energy by the time it reaches the end turns of spiral 49 and helix 11 adjacent the dual conductor parallel transmission line formed by conductors 43 and 50. The conductors 43 and 50 supply the aforementioned energy to the coaxial line connector 45 to which an output coaxial line, not shown, would be connected for transfer of amplified microwave signal energy to a suitable load. Although not illustrated in the drawings, it should be understood that feedback of signal energy along helix 11 which might cause oscillations should be precluded by suitable lossy attenuating material means along an intermediate region along helix 11, for example.

The output transition section comprising the spiral conductor 49 and helical conductor 44 function in a manner generally similar to the input transition section comprising spiral conductor 39 and the portion of helix 11 therewithin. The coaxial line connector 45 has a characteristic impedance of about fifty ohms, for example. The impedance between the end turns of spiral 49 nearest collector 21 and the adjacent turns of helical conductor 44 and the impedance between conductive portions 43 and 50 as a transmission line should be approximately the same as connector 45. The radii and spacings between the turns of spiral conductor 49, which may be somewhat flexible, are adjustable as described with reference to conductor 39 for optimizing the transition for a particular frequency or frequency band. Generally, the axial extent of spiral conductor 49 is at least one wavelength of helix energy for the lowest frequency of operation, the wider end thereof being just outside the effective radial extent of the useful electric field of helix 11 for the helix mode of operation.

As has been mentioned above, magnetic means must be employed with the aforedescribed travelling wave tube for maintaining the electron beam along the helix 11 so that it has a constant diameter. This may be done by utilizing conventional solenoid or permanent magnet focusing means as employed with many travelling wave tube devices known in the art for establishing an axial magnetic focusing field between accelerator electrode

17 acting as a pole piece and a further apertured pole piece in the vicinity of the output end of the tube, not shown in the drawings. An alternative mode of focusing, which is particularly advantageous with the present tube as shown in the drawings wherein no magnetic pole pieces or solenoids are required, is to provide means for establishing a pulsed magnetic beam controlling field for use when the electron beam is pulsed as disclosed in applicant's U. S. application S. N. 197,535, filed November 25, 1950, now Patent No. 2,789,246, issued April 16, 1957. The elements for providing a pulsed magnetic field and pulsed beam are shown in block form in the drawings, such elements being similar to the corresponding elements in Patent No. 2,789,246 designated by the same reference numerals.

Referring now to the present drawings, the magnetizing pulse generator 63 is connected by output leads 64 and 66 to opposite ends of helix 11. One end of helix 11 is connected to lead 66 by virtue of the conductive extension 28 therefrom connected to metallic vacuum sealing ring 27. Lead 66 is soldered to ring 27. The other end of helix 11 is connected to lead 64 via conductor portion 37, the inner conductors of coaxial line connector 30 and coaxial line 33 and the inner conductor of stub line 52. Lead 64 is soldered to the end of the inner conductor of the stub line 52, for example. Generator 63 is adapted to produce intense D. C. pulses of current for passage along the helix 11 to establish a pulsed magnetic focusing field of sufficient density for maintaining a constant diameter beam, the beam being pulsed in synchronism with the pulsed magnetic field as disclosed in the foregoing Patent No. 2,789,246.

It can readily be seen that the provisions of the stub line 52 permit the lead 64 of generator 63, which may be at ground potential, to be connected to the travelling wave tube helix 11. Also the fact that the microwave output from the device is derived by mutual coupling of helix 11 to helical conductor 47 with no direct connection of helix 11 to an output transmission line, permits the other end of helix 11 to be connected directly to the lead 66 of generator 63 without effecting the R. F. output. It should be apparent that the input and output for exchange of microwave energy with the helix 11 could be reversed with each other along the tube, if desired, or that a hollow wave guide or an adjustable resonator output could be utilized at the output end of the tube for deriving microwave energy from the tube by mutual coupling.

The synchronizer 62 is employed for providing regularly recurring sharp pulses at a radar frequency repetition rate for triggering the pulse generator 63 and for triggering a pulsed power supply 67 whose voltage output is connected by leads 69 and 71 to the cathode and accelerator electrodes respectively, of the electron gun 15. The power supply 67 and generator 63 are monostable devices, the power supply 67 producing a rectangular voltage pulse of predetermined width such as one microsecond for each pulse trigger from synchronizer 62. The generator 63 should produce a current pulse approximating that of a half sine wave for each trigger pulse.

The delay circuit 68 is provided between power supply 67 and synchronizer 62 for insuring that the magnetizing current supplied to helix 11 begins somewhat in advance of the pulses of beam current. The generator 63 is regulated so that its trailing edge occurs after the beam pulse as disclosed in the aforementioned Patent No. 2,789,246. Generally, the half sine wave current pulses from generator 63 should have a duration of the order of four times that of the beam pulses.

The R. F. transmitter 51 may also be pulsed in synchronism with the beam, and may comprise any conventional transmitter such as a klystron which is readily adapted to be pulsed by a trigger such as is available at

the output of delay circuit **68**. Thus, the transmitter **51** is shown as connected to the output of delay circuit **68** for receiving a trigger pulse therefrom.

It can be readily seen that the matching sections **39** and **49** cannot comprise a shorted turn about the helix **11** as to preclude the use of a pulsed magnetic focusing field. Furthermore, since the characteristics of the sections **39** and **49** can be adjusted, the arrangement is particularly advantageous over that disclosed in Patent No. 2,789,246 wherein it would be desirable to enhance the transfer of energy between the dual conductor transmission lines and helix **11**.

Although the accelerator electrode **20** and the tubular extension therefrom which surrounds the cathode of the electron gun are disclosed as being of magnetically permeable material, they could be made of highly conductive non-ferromagnetic material such as copper or silver if pulsed magnetic focusing is employed. This is the case even though one of the requirements for member **20** and the tubular extension therefrom is to magnetically shield the gun cathode from the magnetic focusing field. The foregoing requirement is met where a pulsed magnetic field is employed, even if member **20** were of highly conductive non-ferromagnetic material since member **20** comprises a shorted turn about the tube axis. Therefore, eddy currents induced in member **20** by the pulsed magnetic field cause the member **20** to act as a shielding element, even if of copper or silver, and precludes any effective magnetic flux from the cathode region of the gun **15**. Although the member **20** comprises a shorted turn as aforedescribed, it has no appreciable affect on the axial component of the magnetic beam focusing field along the magnetizing current carrying helix **11** as it is sufficiently spaced axially from helix **11** so as to be only loosely coupled thereto.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. A travelling wave tube, comprising a conductive helix extending along a predetermined axis, means positioned at one end of said helix for producing and directing an electron beam along said helix, coupling means along said helix for the exchange of microwave energy between said helix and an external microwave device, said coupling means including a spiral conductor disposed about an end region of said helix in spaced relationship with the turns of said helix, the radii of the turns of said spiral conductor along said helix increasing relative to the radii of the adjacent turns of said helix in the direction of an intermediate region of said helix, a dual conductor transmission line section having one conductor coupled in electromagnetic energy exchanging relationship with said helix, said transmission line section having a further conductor connected to the smaller end of said spiral conductor, and a coaxial line having inner and outer conductors, said inner conductor being connected to said one conductor and said outer conductor being connected to said further conductor of said dual conductor transmission line.

2. A travelling wave tube as set forth in claim 1, including a helical conductor section intermediate said helix and spiral conductor in insulated relationship therewith, one end of said helical conductor section being connected to said one conductor of said dual conductor transmission line section, whereby said helix is coupled to said one conductor of said dual conductor transmission line by mutual electromagnetic coupling between said helical conductor section and helix.

3. A travelling wave tube as set forth in claim 1, wherein said one conductor of said dual conductor transmission line section is connected directly to an end of said helix.

4. A travelling wave tube as set forth in claim 1, further including an evacuated tubular envelope of dielectric material, said helix being supported within said envelope with said spiral conductor being disposed externally of said envelope, said spiral conductor being flexible for changing the spacings between and radii of the turns thereof.

5. A travelling wave tube, comprising a conductive helix for the propagation of slow wave electromagnetic energy, means for producing and directing an electron beam along said helix for interaction with helix electromagnetic energy, a section of coaxial transmission line having inner and outer conductors, and means including a spiral conductor disposed about said helix for coupling of microwave energy between said helix and said section of transmission line, said spiral conductor being connected to the outer conductor of said transmission line with said helix being connected to the inner conductor of said coaxial transmission line.

6. A travelling wave tube as set forth in claim 5, further including means connected to the ends of said helix for pulsing said helix with magnetizing current for establishing a beam controlling magnetic field for preserving the configuration of said electron beam along said helix.

7. A travelling wave tube as set forth in claim 6, further including a helical conductor section between said helix and spiral conductor in insulated relationship therewith, said helical conductor section extending along an end region of said helix with one end of said section being connected to the inner conductor of said transmission line, an end of said spiral conductor adjacent said one end of said helical conductor section being connected to the outer conductor of said transmission line.

8. A travelling wave tube, comprising means defining an evacuated envelope, a conductive helix supported within said envelope, an electron gun positioned at one end of said helix for producing and directing an electron beam along said helix, a section of coaxial transmission line, means coupling the inner conductor of said transmission line to said helix, conductor means enveloping an end region of said helix, said conductor means having metallic surfaces and spaced by an increasing amount from said helix proceeding along said helix toward an intermediate region thereof, means connecting said conductor means to the outer conductor of said coaxial transmission line section, the metallic surfaces of said conductor means being spaced from said helix by said increasing amount for providing an impedance match between said helix and said coaxial line for microwave energy, said surfaces being spaced from each other for precluding a shorted turn about said helix, and means coupled to the ends of said helix for pulsing said helix with magnetizing current for establishing a beam controlling magnetic field to preserve the configuration of said beam along said helix.

9. A travelling wave tube as set forth in claim 8, wherein said conductor means enveloping said helix comprises a spiral conductor whose turns are of slightly larger diameter than the turns of said helix at the end of said conductor means connected to said coaxial line, the radii of the turns of said spiral conductor further along said conductor means from said one end thereof becoming increasingly larger.

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