

[54] **HELIX DELAY LINE FOR TRAVELING WAVE DEVICES**
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[22] Filed: **Feb. 24, 1971**
[21] Appl. No.: **118,256**

[52] **U.S. Cl.**.....**315/3.5, 333/31, 315/3.6, 29/600**
[51] **Int. Cl.**.....**H01j 25/34**
[58] **Field of Search**.....**29/599, 600; 315/3.5, 3.6; 331/31 A**

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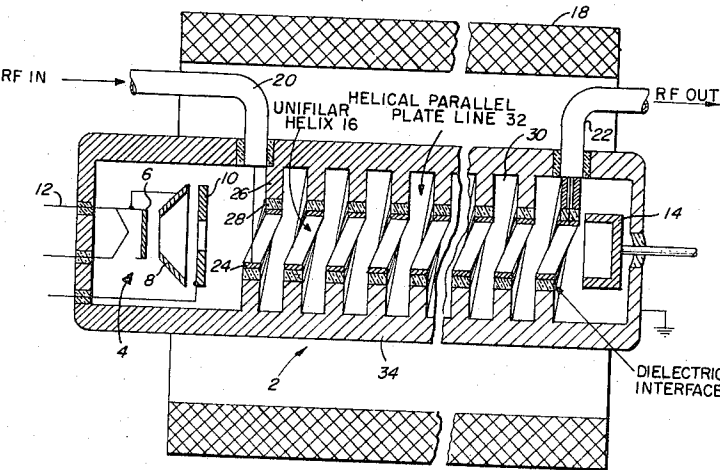
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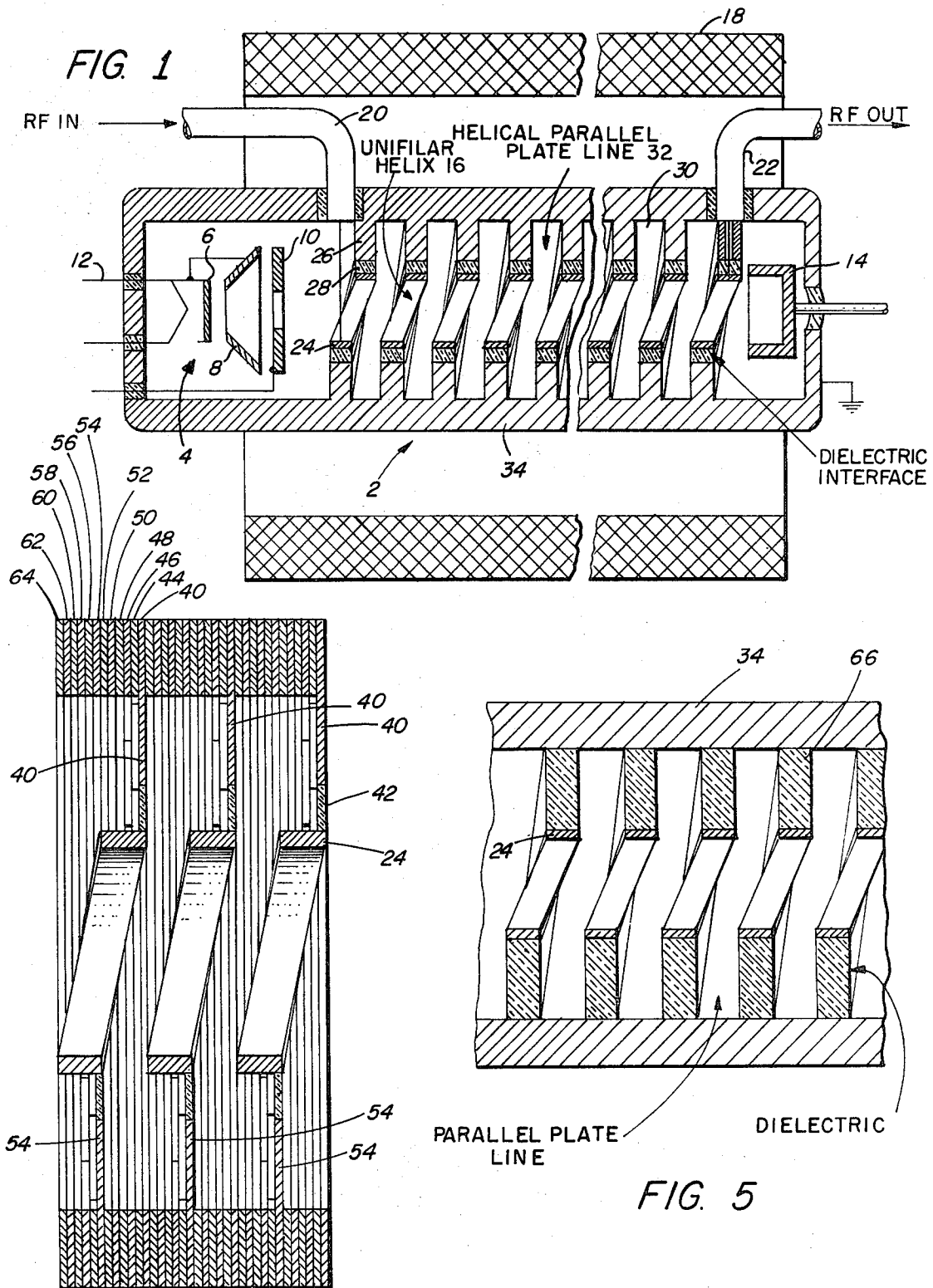
Primary Examiner—Herman Karl Saalbach
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[57] **ABSTRACT**

A helix type wave propagating delay line structure for high power broadband traveling wave devices is disclosed having a parallel plate transmission line support arrangement with a dielectric interface. Improved thermal energy dissipation is provided with a minimum of disruption of the electrical circuit parameters necessary for electron beam-RF wave interaction. The phase velocity characteristics of the parallel plate support and helix delay line structures are substantially similar.

13 Claims, 13 Drawing Figures





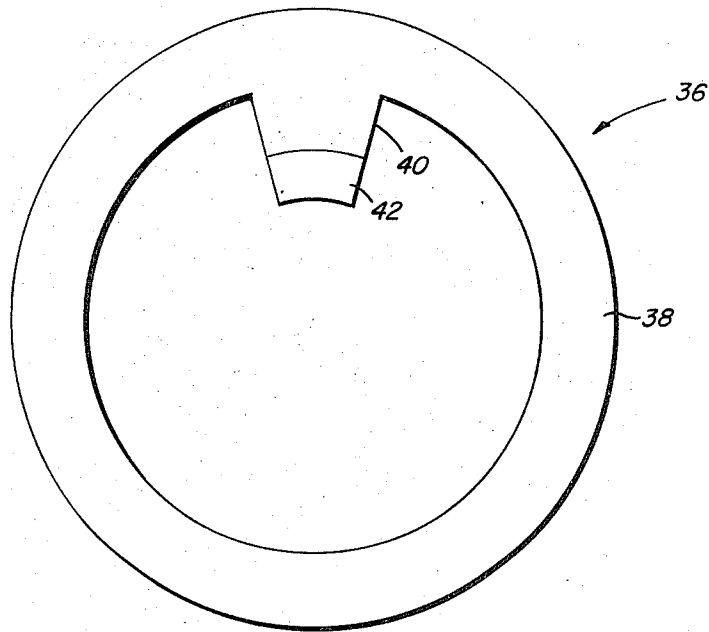


FIG. 3

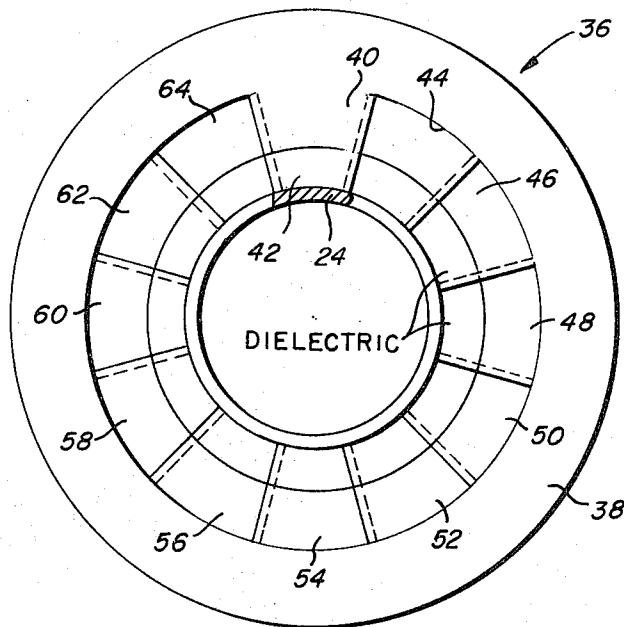


FIG. 4

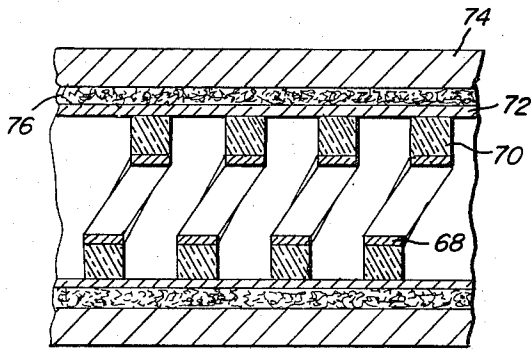


FIG. 6

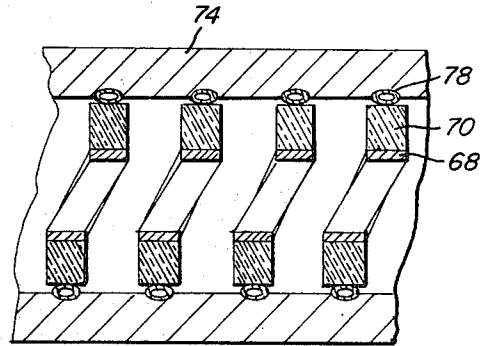


FIG. 7

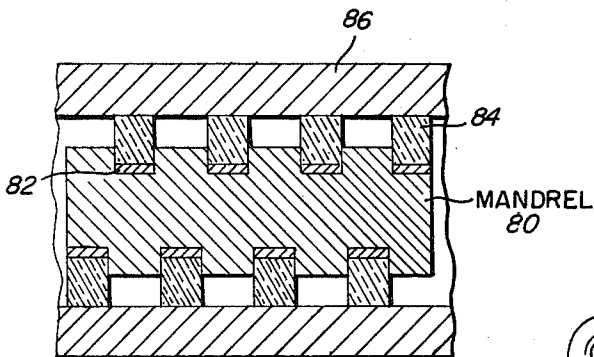


FIG. 8

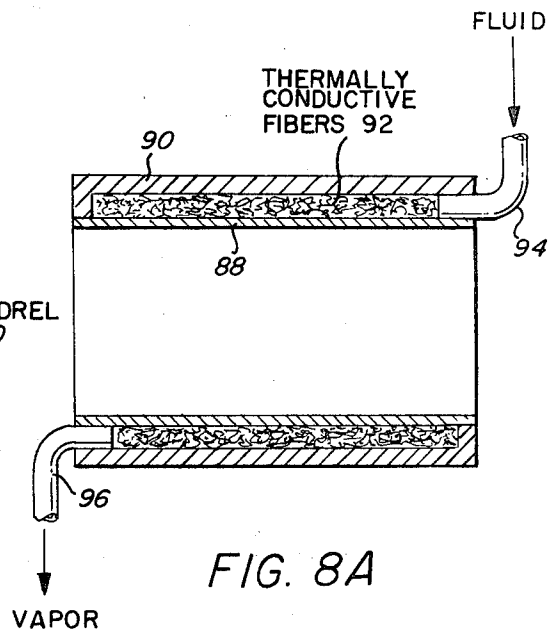


FIG. 8A

FIG. 8B

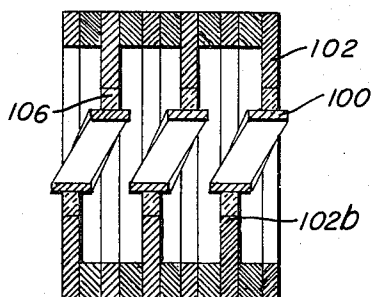
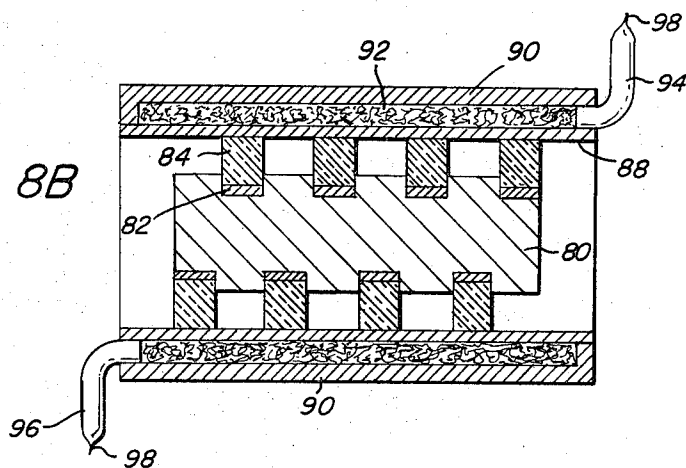


FIG. 9

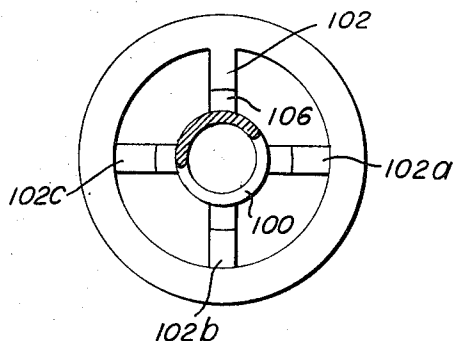


FIG. 10

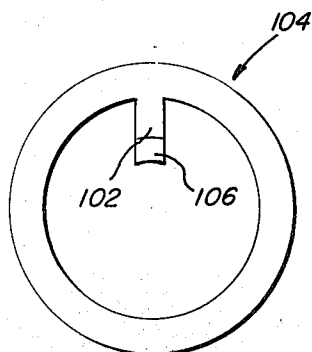


FIG. 11

HELIX DELAY LINE FOR TRAVELING WAVE DEVICES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a helix type wave propagating delay line having high thermal dissipation characteristics for traveling wave devices.

2. Description of the Prior Art

Traveling wave devices commonly employ delay line propagating structures having a plurality of periodic circuit elements to reduce the velocity of RF electromagnetic waves and permit interaction with an electron beam to result in a net exchange of energy. The establishment of a synchronous relationship between the electron beam velocity and the space harmonics of the traveling wave circuit determines the interaction phenomenon.

An exemplary device incorporating a periodic delay line structure is referred to in the art as the O-type. Such devices operate on the principle of the interchange of kinetic energy of the electrons with the electric fields of the electromagnetic circuit waves. The combined fields induce perturbations in the electron beam to form electron packets which exchange energy with the electromagnetic circuit waves to result in amplification of high frequency RF energy. A delay line structure commonly employed in traveling wave amplifiers is a helix having a plurality of continuously wound tape or wire conductive circuit elements in both a unifilar or bifilar arrangement with broad bandwidth capabilities and high gain per unit length. For average RF output powers, generally over several kilowatts, the helix type delay line becomes excessively heated by beam interception and RF losses and, therefore, is employed only at low power levels.

The utilization of helix type delay line structures for higher power output devices is strongly dependent on efficient thermal dissipation. Another factor to be considered in traveling wave amplification is the requirement for preventing oscillation due to reflected energy by introducing lump attenuator lossy structures such as parallel ceramic or glass rods supporting the helix. Such lossy structures, however, are poor thermal conductors which renders the devices less attractive for high power broad band microwave systems. Additional structures such as conduits, conductive supports and the like with systems for circulation of fluid coolants have also been proposed for helix delay lines, however, the result has been a restriction in bandwidth.

It is desirable, therefore, for the advancement of present day communication systems to provide traveling wave devices capable of broad bandwidths as well as the higher power outputs. The efficiencies of helix type delay line structures together with broad bandwidths coupled with improved thermal energy dissipation will lead to the evolution of higher power traveling wave devices.

SUMMARY OF THE INVENTION

In accordance with the teachings of the invention, a helix type delay line is provided with each circuit element being supported by thermally conductive dissipation means. In some illustrative embodiments, thermal energy dissipation members are joined directly to dielectric interface means and define a combined envelope and coaxial helical parallel plate transmission line having substantially the same phase velocity characteristics as the principal helix delay line. Other illustrative embodiments disclose dielectric interface means joined to a thermally conductive envelope to thereby provide a coaxial helical parallel plate transmission line support structure having similar phase velocity characteristics as the helix delay line circuit. In this manner a new and novel wave propagating structure has evolved wherein there is no dielectric material bridging adjacent helix circuit elements. Such bridging is commonly found in prior art helix delay line structures wherein elongated dielectric rod support members simultaneously engage all the circuit elements and are disposed parallel to the longitudinal axis of the helix. With the present structure an

equivalent parallel plate transmission line is provided with a plurality of radially extending members of a dielectric or combined dielectric and thermally conductive material composition together with a conductive envelope. The helix coupling impedance has been maintained for the prerequisite beam-to-wave circuit interaction of a conventional sheath helix. The thermal dissipation characteristics, however, have been vastly improved to enhance power handling capabilities by factors of twofold or better.

A series of lamination members which are readily stacked and brazed to a helix will yield the new delay line structure. Many other fabrication techniques are described herein to provide the dielectric-to-thermally conductive material interface and enhance thermal dissipation characteristics. Such techniques also provide means for the circulation of a fluid coolant during operation of the traveling wave device. Stub-supported helix delay lines are also described having angularly displaced radial conductive supports sequentially disposed to further simplify fabrication.

The electric parameters of the helix delay line can be readily determined analytically by computer techniques and the coaxial helical thermal dissipation parallel plate type support structure mechanical parameters can then be determined.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, as well as the details for the provision of a preferred embodiment, will be readily understood after consideration of the following detailed description and reference to the accompanying drawings, wherein:

FIG. 1 is a cross-sectional view of a traveling wave device utilizing the helix delay line structure of the present invention;

FIG. 2 is an enlarged cross-sectional view of a portion of a helix delay line fabricated in accordance with stacked lamination techniques;

FIG. 3 is an elevation of the lamination member utilized in the embodiment shown in FIG. 2;

FIG. 4 is an end view of the helix delay line array utilizing the stacked lamination technique;

FIG. 5 is a cross-sectional view of a portion of an alternative helix delay line structure having a helical dielectric parallel plate transmission line support arrangement;

FIG. 6 is a cross-sectional view illustrative of one fabrication technique for another alternative helix delay line structure;

FIG. 7 is a cross-sectional view illustrative of still another alternative technique for the fabrication of a helix delay line structure;

FIGS. 8, 8A and 8B are cross-sectional views illustrative of the steps in the fabrication of the helix structure illustrated in FIG. 6;

FIG. 9 is a cross-sectional view of a stub-supported helix delay line structure;

FIG. 10 is an end view of the helix delay line assembly shown in FIG. 9; and

FIG. 11 is an elevation of the lamination member utilized in the embodiment shown in FIG. 9.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The traveling wave device 2 incorporating the embodiment of the invention is shown in FIG. 1. At one end an electron gun assembly 4 is provided having a cathode 6, focusing electrode 8 and an accelerating anode 10. Appropriate DC voltages necessary for the operation of the device and the electron gun are coupled through leads 12. A collector electrode 14 is provided at the opposing end of the device to intercept and dissipate the electrons in the beam after traversing the path defined by the helix delay line structure 16 which is illustrated as being of the unifilar configuration.

Electromagnetic means 18 surround the device and provide a magnetic field to assist in the propagation of the electron beam along the longitudinal axis of the helix delay line 16. In the illustrative embodiment a traveling wave amplifier is

shown and the RF energy to be amplified is coupled to the helix delay line by an input transmission line 20. An output transmission line 22 is coupled to the collector end of the device. Numerous systems for the circulation of a fluid coolant around the traveling wave device or through the elements of the helix delay line may be employed. Such cooling systems have been purposely omitted in this description to aid in an understanding of the overall invention.

Helical delay line 16 includes a continuously wound conductive wire or tape defining a plurality of elements 24 having a predetermined periodicity to evolve the sheath helix model conventionally employed in traveling wave devices. Coaxial thermal dissipation and support structure defined by a plurality of radially inwardly extending lands 26 having a dielectric material interface 28 at the tip contacts the outer wall surfaces of the delay line elements 24. Alternate spaces 30 between adjacent lands also define a periodic structure similar to that of the helix delay line 16. In this manner a coaxial helical parallel plate transmission line 32 extends coextensive with the delay line. This line provides substantially the same electrical dispersion characteristics as the principal helix delay line with the addition of some related propagation modes. A retaining shell member 34 of a conductive material extends throughout the length of the traveling wave device and serves as a portion of the parallel plate transmission line 32 as well as a vacuum tight envelope for the overall traveling wave device. The dielectric interface means comprises any suitable dielectric or ceramic lossy material which may be bonded to the inner ends of the lands 26 and in turn to the outer surfaces of the helix delay line elements 24. One such material includes the ceramic material, beryllia, which may be provided in strip form having a width substantially equal to the width of the tape helix delay line elements 24.

A method of fabricating the delay line structure of the invention utilizing stacked lamination techniques will now be described with reference being directed to FIGS. 2-4 inclusive. In FIG. 3 a lamination circuit element 36 of a highly conductive metal such as copper defines a circular body portion 38 and an inwardly extending radial land 40. Lamination 36 may be fabricated by metal punching and a wafer 42 of a ceramic composition is soldered or otherwise secured to the inner tip.

In FIG. 4 an end view is shown of a stacked lamination array with each radial land and dielectric interface portion being sequentially angularly displaced from its companion member to form the coaxial helical parallel plate transmission line supporting delay line 16. In each series the first land 40 is vertical. The underlying lamination element providing land 44 is displaced, as shown, and each succeeding land assumes a position circumferentially engaging the delay line elements 24 in a helical manner to thereby define the coaxial helical parallel plate transmission line 32. In this embodiment, each land of the lamination element covers approximately a 30° sector of the helix delay line elements.

In FIG. 2 the overall array is illustrated and for each period of the helix, 12 lamination elements will be utilized with the land portions sequentially angularly displaced in one complete revolution. Following the pattern suggested in this array, the land portions of the succeeding lamination elements have been designated by the even numerals 46-64 inclusive. The delay line structure may be readily fabricated utilizing a mandrel together with radial pins to insure that the pitch of the helix elements and the helical parallel plate line support structure are substantially equivalent. The dielectric interface means may be provided by ceramic strips having a width substantially similar to that of the tape helix elements 24. The conductive metal laminations can then be secured to the interface means in a subsequent operation.

The delay line and coaxial helical parallel plate support structure have substantially the equivalent electrical dispersion characteristics of a sheath helix. A stop band, however, occurs whenever the radial length of the lands is a multiple of a half wavelength. This mode can be damped by placing lossy

material at appropriate points at the root of the lands involved. The delay line structure of the present invention is ideally suited for broadband traveling wave devices which can operate in a band of illustratively 7.0 to 11.0 GHz. To provide the desired dispersion characteristics, the coaxial parallel plate transmission line defined between the lands has a length of one-quarter of a wavelength at the center band of the frequency range or 9.0 GHz. With such a structure the helix coupling impedance would be substantially unaffected at the center frequency when the radial electrical length of the parallel plate transmission line was one-half of a wavelength. At the extremes of the frequency range, however, the parallel plate transmission line may have a significant influence on the helix coupling impedance. A uniform impedance characteristic may be readily provided by varying the radial length of the parallel plate transmission line in a programmed fashion with the radius of the parallel plate line being smaller at the low frequency end of the band and larger at the high frequency extremity. It will be noted in comparison with conventional prior art helix delay lines that there is no dielectric material bridging adjacent helix delay line elements.

In FIG. 5 an alternative embodiment is shown wherein the radial length of the coaxial helical parallel plate line is now equal to zero with dielectric interface members 66 spanning the region between helix delay line elements 24 and retaining shell 34. This embodiment provides certain advantages mechanically over the embodiments previously described while maintaining the dispersion characteristics at a value substantially equal to the prior art dielectric rod supported helix delay lines. The thermal energy dissipation capability of the new structure, however, is approximately twofold that of the prior art embodiments. Dielectric members 66 in this embodiment may be provided by a continuous ribbon of a suitable dielectric or ceramic material wound on a mandrel supporting the helix delay line of conductive metal and brazing or welding the assembled components. It is also within the purview of the invention to provide a ceramic cylindrical body metallized on the inner and outer surfaces with the desired pitch angle matching that of the helix delay line period cut into the ceramic body. Numerous other methods and techniques will readily be evident to those skilled in the art.

FIG. 6 is a view of an embodiment of the invention incorporating both a thermal energy dissipation system as well as compression bonding of the dielectric interface means to the helix delay line elements. In this embodiment the helix delay line elements 68 have secured to the outer surfaces thereof dielectric members 70. A relatively thin wall 72 of a conductive material forms with outer retaining wall member 74 an annular chamber which is filled with, illustratively, a plurality of thermally conductive bodies 76. By providing a fluid within the chamber, the high brazing temperature required for the bonding of the dielectric and metallic members will result in a high vapor pressure thereby expanding the chamber wall 72 to exert a compressive force upon the interface surfaces of the members to be bonded. The annular chamber may be sealed and become an integral part of the overall traveling wave device or it may be coupled with an auxiliary fluid coolant circulation system to be utilized both during the fabrication of the helical delay line structure as well as the operation of the traveling wave device. The embodiment disclosed herein is ideally suited for the fabrication of delay line structures having a relatively small radius and narrow tape element width. Metallic fibers or irregular shaped bodies or cylindrical members such as copper balls may be utilized to fill the annular chamber to enhance the heat transfer involved in this procedure.

Another embodiment incorporating an integral compression exerting means as well as fluid coolant circulation means is disclosed in FIG. 7 and is suited for relatively larger delay lines. In this view the dielectric interface members 70 are provided with a helical tubular copper conduit having a pitch equal to or less than the pitch of the principal helix delay line. Again, as in the preceding view, the conduit may be employed

for circulation of a coolant after the device is placed in operation. The conduit may be mounted within helical grooves in the retaining shell member 74 conforming to the cylindrical surfaces of the outer walls of the conduit. Again, as in the previous embodiments, a beryllium oxide body suitably machined to provide the prerequisite pitch angle of members 70 can be provided as a separate assembly with a metallized coating on the inner surfaces to be bonded to the helix elements and on the outer surfaces for bonding to shell member 74.

Referring next to FIGS. 8, 8A and 8B, the sequence of operations in the fabrication of the helix delay line structure illustrated in FIG. 6 is shown. FIG. 8 is a view of the assembled helix and dielectric parallel plate line mounted within a jig fixture. Mandrel 80 of a material such as stainless steel is provided with a plurality of grooves conforming to the desired pitch of the helix. A tape helix of, illustratively, copper, comprising a plurality of elements 82 is continuously wound on the mandrel 80. A dielectric interface body 84 with a suitable metallization in the bonding region is then positioned in contiguous engagement with the helix elements 82. A brazing shell 86 may then be positioned to retain the components for insertion in a brazing furnace at an elevated temperature to complete the dielectric to helix assembly. Shell 86 may be fabricated of a high temperature metal such as molybdenum and is removed after the dielectric and helix members have been brazed. Another subassembly FIG. 8A comprises a relatively thin inner tubular member 88 of copper having secured thereto an outer shell 90 of a material such as cupronickel to define therewith an annular vapor chamber filled with thermally conductive bodies 92. Inlet 94 provides for the introduction of a fluid within the vapor chamber which upon being exposed to high temperatures results in deformation of inner member 88 radially to thereby exert a compressive force upon any underlying structure.

In FIG. 8B the brazed helix and dielectric interface body assembly mounted on the mandrel as shown in FIG. 8 is mounted within the subassembly illustrated in FIG. 8A. A metallizing material disposed on the outer wall surfaces of dielectric interface body 84 will upon brazing result in a unitary integral final assembly. After removal of the mandrel 80 the helix delay line structure and adjacent parallel plate transmission line shown in FIG. 6 will be realized. The inlet and outlet conduits may be terminated as at 98 if no additional use is to be made of the vapor chamber defined between the members 88 and 90.

FIGS. 9-11 inclusive illustrate another delay line configuration embodying the principles of the invention. In this embodiment each period of the helix delay line 100 is supported by four stubs 102 perpendicularly disposed relative to each other. A lamination 104 has a radial stub portion 102 together with an inner dielectric interface 106 which is joined to the helix elements in the desired angular displacement pattern. Referring to FIG. 10, stub 102 would then be in the upright position while the underlying stub 102a is rotated 90° from the original position. The next succeeding lamination having stub portion 102b would be disposed 180° from the original position. Next stub portion 102c is disposed 180° from the stub 102a. The array may then be completed by securing the laminations 104 to each other. The spatial orientation of stubs 102 may result in a slight sacrifice in bandwidth compared to preceding embodiments however the fabrication is simplified. Further, as is true in all the illustrative embodiments, high thermal energy dissipation is realized compared to prior art helix delay line structures.

Several modifications and variations in the pertinent delay line structures have been described herein. Numerous other modifications will be readily apparent to those skilled in the art. It is intended, therefore, that the foregoing description be considered in the broadest aspects and not in a limiting sense.

What is claimed is:

1. A traveling wave device comprising:

a helical periodic electromagnetic wave energy propagating structure having predetermined electrical characteristics over a predetermined frequency range;

means for generating and directing a beam of electrons adjacent to said propagating structure; and

a plurality of continuously connected support means disposed coextensive with and contacting said wave propagating structure;

said support means defining therebetween a helical parallel plate transmission line having substantially the same electrical characteristics as said wave propagating structure.

2. A traveling wave device comprising:

a plurality of continuously wound circuit elements forming a helical periodic electromagnetic wave energy propagating structure having predetermined pitch and phase velocity characteristics;

means for generating and directing a beam of electrons along the longitudinal axis of said wave propagating structure; and

a plurality of continuously connected support means disposed coextensive with and contacting each of said circuit elements;

said support means defining therebetween a helical parallel plate transmission line having substantially the same pitch and phase velocity characteristics as said wave propagating structure.

3. A device according to claim 2 wherein said support means define interface means of a dielectric material contacting each circuit element.

4. A traveling wave device comprising:

an envelope;

a plurality of continuously wound circuit elements forming a helical periodic electromagnetic wave energy propagating structure having predetermined pitch and phase velocity characteristics;

means for generating and directing a beam of electrons along the longitudinal axis of said wave propagating structure; and

a plurality of continuously connected support means contacting each of said circuit elements and said envelope;

said support means defining therebetween a coaxial helical parallel plate transmission line having substantially the same pitch and phase velocity characteristics as said wave propagating structure.

5. A device according to claim 4 wherein said envelope comprises an annular chamber and means for circulating a fluid medium within said chamber.

6. A device according to claim 5 wherein said chamber is substantially filled with a plurality of thermally conductive bodies.

7. A device according to claim 4 wherein a tubular conduit is disposed between said envelope and support means with said conduit being coupled to means for circulating a fluid medium.

8. A traveling wave device comprising:

an envelope;

a plurality of continuously wound circuit elements forming a helical electromagnetic wave energy propagating structure having a predetermined periodicity;

means for generating and directing a beam of electrons along the longitudinal axis of said wave propagating structure; and

a plurality of conductive lamination members having radial land portions angularly displaced in a predetermined manner to define a substantially helical support array with each of said land portions contacting a circuit element;

said land portions defining therebetween a coaxial substantially helical parallel plate transmission line having substantially the same periodicity as said wave propagating structure.

9. A device according to claim 8 wherein said lamination members have a circular body portion collectively defining a

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portion of said envelope when said members are joined together.

10. A device according to claim 8 wherein each of said radial land portions define an interface of a dielectric material adjacent to the circuit elements.

11. A device according to claim 8 wherein each of said lamination members comprise a substantially circular body of a conductive material and a radial land portion of a dielectric

material.

12. A device according to claim 8 wherein each of said land portions define a sector having an angular dimension of approximately 30°.

13. A device according to claim 8 wherein said land portions are disposed substantially mutually perpendicular to each other.

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