

[54] **ANISOTROPIC SHELL LOADING OF HIGH POWER HELIX TRAVELING WAVE TUBES**

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[51] Int. Cl.² **H01J 25/34**

[58] Field of Search..... **315/3.5, 3.6, 39.3; 330/43**

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[57] **ABSTRACT**

The helix of a high power traveling wave tube, i.e., in excess of ten watts cw, is supported from a thermally conductive barrel-shaped metallic envelope via the intermediary of a plurality of beryllia or boron nitride rods disposed at circumferentially spaced locations around the periphery of the helix. The helix is anisotropically loaded for decreasing the positive dispersion or, in the alternative, producing a negative dispersion characteristic by means of a loading structure disposed surrounding the helix intermediate the helix and the barrel structure. In one embodiment, the loading structure comprises a plurality of arcuate quartz sectors having an array of longitudinally directed electrically conductive elements supported on the inside surface thereof adjacent the helix. In a second embodiment, the loading structure comprises a plurality of arcuate alumina sectors interposed between the helix and the surrounding barrel structure. These loading elements of both types greatly increase the operating bandwidth over which relatively high gain and efficiency are obtainable.

5 Claims, 11 Drawing Figures

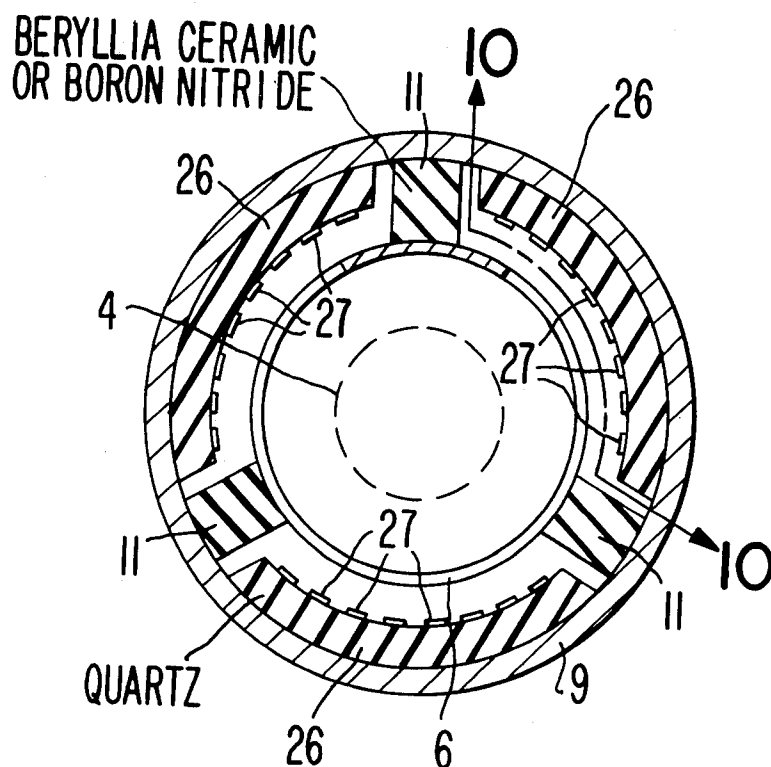


FIG. 1
PRIOR ART

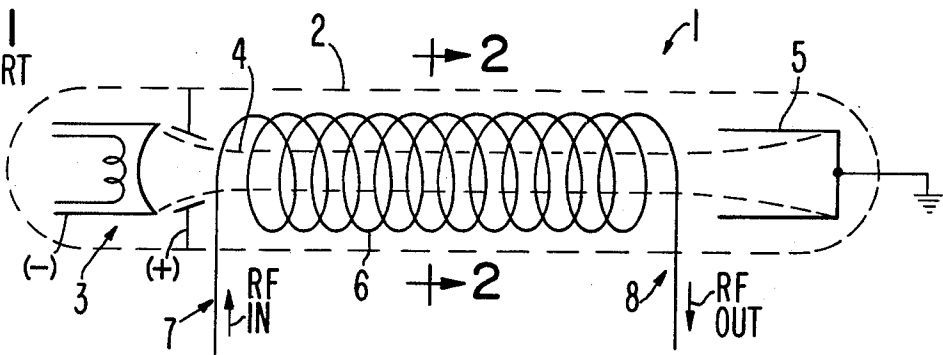
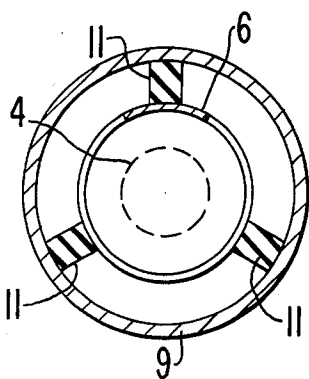


FIG. 2
PRIOR ART

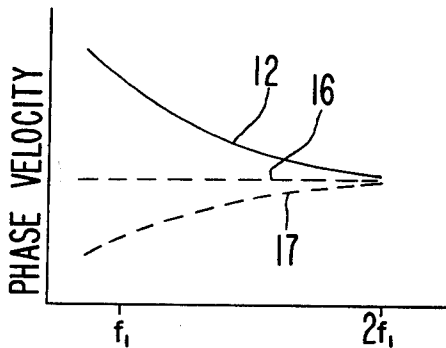


FIG. 3

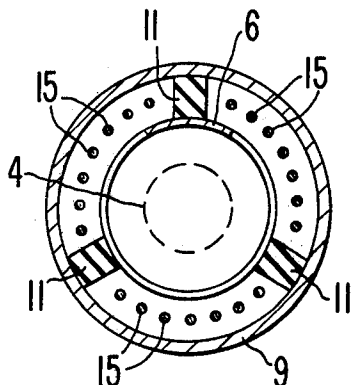


FIG. 4
PRIOR ART

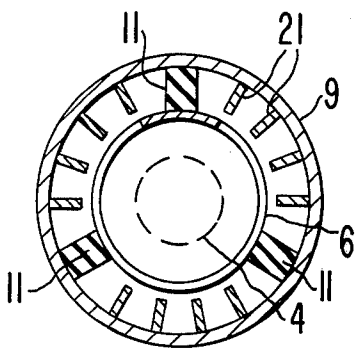


FIG. 5
PRIOR ART

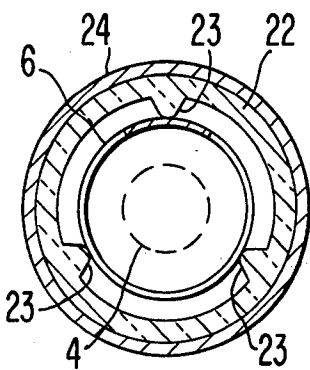


FIG. 6
PRIOR ART

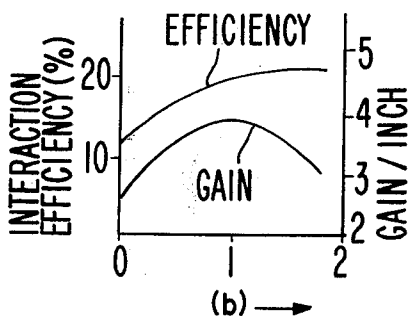


FIG. 7

ANISOTROPIC SHELL LOADING OF HIGH POWER HELIX TRAVELING WAVE TUBES

BACKGROUND OF THE INVENTION

The present invention relates in general to anisotropic shell loading of high power helix traveling wave tubes and, more particularly, to such loading elements which are readily physically realizable for high power applications, i.e., cw power outputs in the range of 10 watts to several kilowatts.

DESCRIPTION OF THE PRIOR ART

Heretofore, it has been proposed to anisotropically shell load the helix of a traveling wave tube by arranging an array of fine wires extending lengthwise of the helix and surrounding the helix in spaced relation, such wires being disposed between the helix and a surrounding electrically conductive barrel structure. Theory predicted that such anisotropic shell loading of the helix would greatly improve the operating bandwidth over which relatively high gain and efficiency could be obtained by reducing the positive dispersion of the helix structure. The problem with this theoretical approach was that there was no practical way proposed for supporting the array of conductive wires around the helix.

In another prior art tube it was proposed to simulate the array of conductive wires by an array of electrically conductive vanes projecting toward the helix from a surrounding barrel structure, such vanes extending lengthwise of the helix. While such an arrangement provides some degree of anisotropic shell loading, it was less than entirely satisfactory because at relatively high frequencies, i.e., in the microwave range of S-band and above, the vanes became very small and only a relatively small number of such vanes could be accommodated around the helix such number being for example 12 to 16. This number of vanes did not provide enough loading.

It was also proposed in the prior art to anisotropically shell load a helix of a low power traveling wave tube by extruding the inside wall of the glass envelope of the tube with a plurality of flutes projecting inwardly for supporting the helix in spaced relation to a relatively heavy glass wall. The relatively heavy glass wall served to anisotropically load the helix for improving the bandwidth over which relatively high gain and efficiency could be obtained. This structure turned out to be practical at low powers but could not be extended to high power because glass envelopes are not suitable for high power applications due to their relatively poor thermal conductivity. More specifically, due to the poor thermal conductivity of the helix support structure at high power applications, i.e., over ten watts cw, the helix intercepts substantial power which produces heating thereof. Because the heat cannot be conducted from the helix the helix reaches excessive operating temperatures and results in failure of the helix and therefore failure of the tube.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of a high power helix traveling wave tube having increased bandwidth over which relatively high efficiency and gain are achieved.

In one feature of the present invention, anisotropic shell loading of the helix structure is obtained by use of a plurality of arcuate quartz sectors surrounding the helix in spaced relation therefrom, such quartz sectors supporting an array of longitudinally directed conductive elements on the surface thereof facing the helix for adding a negative dispersion loading effect to the otherwise positive dispersion characteristic of the traveling wave tube.

In another feature of the present invention, anisotropic shell loading of a helix is provided by means of a plurality of alumina ceramic arcuate sectors disposed surrounding the helix in spaced relation therefrom and in between the helix and the barrel of the traveling wave tube, whereby a negative dispersion component is added to the otherwise positive dispersion characteristic of the traveling wave tube.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal sectional schematic line diagram of a traveling wave tube of the prior art,

FIG. 2 is a transverse sectional view of a physical realization of the structure of FIG. 1 taken along line 2—2 in the direction of the arrows,

FIG. 3 is a plot of phase velocity versus frequency showing the dispersive characteristics for the prior art and for the anisotropically loaded helix of the present invention,

FIG. 4 is a transverse sectional view similar to that of FIG. 2 depicting a dispersion correcting structure of the prior art,

FIG. 5 is a view similar to that of FIG. 4 depicting an alternative embodiment of the prior art,

FIG. 6 is a view similar to that of FIG. 5 depicting an alternative embodiment of the prior art,

FIG. 7 is a plot of interaction efficiency and gain per inch as a function of the velocity synchronism parameter (h),

FIG. 8 is a plot of velocity synchronism parameter (h) as a function of frequency for two values of micropervance and depicting characteristics of the prior art and that of the present invention,

FIG. 9 is a sectional view similar to that of FIG. 2 depicting the anisotropically shell loaded helix of the present invention,

FIG. 10 is a view of a portion of the structure of FIG. 9 taken along line 10—10 in the direction of the arrows, and

FIG. 11 is a view similar to that of FIG. 9 depicting an alternative embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 there is shown the typical traveling wave tube 1 of the prior art. The traveling wave tube 1 includes an elongated evacuated envelope 2 having an electron gun assembly 3 disposed at one end for forming and projecting a beam of electrons 4 over an elongated beam path to a beam collector structure 5 disposed at the terminal end of the beam path and at the other end of the tube 1. A helix slow wave circuit 6 is disposed along the beam path intermediate the electron gun 3 and the beam collector 5 for cumu-

lative electromagnetic interaction with the beam to produce an amplified output signal. More particularly, RF input energy to be amplified is fed onto the helix at the upstream end thereof via an input terminal 7. The microwave energy propagates along the helix in synchronism with the electrons of the beam for cumulative electromagnetic interaction to produce a growing electromagnetic wave on the circuit 6 which is extracted from the circuit at the downstream end via an output terminal 8 and thence fed to a suitable utilization device or load, not shown.

Referring now to FIG. 2 there is shown the typical high power prior art helix support structure. More particularly, the helix 6 is supported from the inside wall of thermally and electrically conductive barrel structure 9, as of copper, which also forms the vacuum envelope of the tube via the intermediary of three electrically insulative thermally conductive refractory rods 11 as of beryllia ceramic or boron nitride. The support rods 11, in one embodiment of the prior art, are captured in an interference fit between the helix 6 and the barrel 9 to provide a good thermally conductive path from the helix to the barrel 9.

Referring now to FIG. 3 there is shown the dispersion curve 12 for the prior art tube of FIGS. 1 and 2. As can be seen from FIG. 3 the helix traveling wave tube has a positive dispersion characteristic over an octave of bandwidth from f_1 to $2f_1$. The basic principle behind traveling wave tube interaction is that the electron beam travels at approximately the same velocity as the microwave signal on the helix so that interaction is continuous along the length of the tube. If this synchronism condition is not exactly satisfied, the tube has poor gain and poor efficiency if it is expected to operate over octave bandwidths.

Referring now to FIG. 8 there is shown a plot of velocity synchronism parameter (b) as a function of frequency for two values of micropervance for the same voltage of the electron beam. As can be seen by solid curves 13 and 14, the velocity synchronism parameter (b) varies widely over the octave of bandwidth, therefore the prior art tube with a positive dispersion characteristic, as shown by curve 12 of FIG. 3, has relatively poor efficiency and gain over the octave of bandwidth.

Referring now to FIG. 7 there is shown the plot of interaction efficiency in percent and gain per inch versus the synchronism parameter (b) showing that maximum gain is obtained for a synchronism parameter (b) value of approximately 1 and the tube has relatively high efficiency for that value. However, the gain falls off on either side of the value of 1 for the synchronism parameter.

It has been proposed in the prior art, as shown in FIG. 4, to anisotropically shell load the helix circuit by disposing an array of longitudinally directed wires 15 around the helix 6 intermediate the helix and the barrel 9. In an optimum design, there would be an infinite number of the very fine wires 15. The wires 15 serve to load the helix in such a manner as to introduce a negative dispersion characteristic to the otherwise positive dispersion characteristic of the helix so that either a flat or negative dispersion characteristic could be obtained by the proper loading as indicated by dotted lines 16 and 17 of FIG. 3.

The anisotropic loading shell 15, as approximated by the multitude of longitudinal wires, is a boundary surrounding the helix which can conduct in the axial direc-

tion but not in the circumferential direction. The theoretical effect of the anisotropic shell on phase velocity is shown by curves 16 and 17 in FIG. 3 and this loading also serves to decrease the interaction impedance generally uniformly over that obtained by the unloaded circuit over wide bandwidths. If the loading is sufficiently great the anisotropic shell shows anomalous or negative dispersion as shown by the curve 17. The exact amount of reduction of the dispersion of the helix depends on how close the anisotropic loading shell is brought to the helix. If just the right ratio of shell diameter to helix diameter is chosen, the dispersion can be completely eliminated as shown by curve 16. However, even better performance can be obtained with the negative dispersion shown by curve 17, which can be obtained by using a different ratio of anisotropic shell diameter to helix diameter.

Although it has been known that an array of tiny wires running axially of the helix, as shown in FIG. 4, could be employed for obtaining the desired negative dispersion, this idea has not been used for traveling wave tubes because of the impracticality of fabricating such an anisotropic loading shell. Attempts have been made to solve this fabrication problem by using an array of metallic vanes 21, as shown in FIG. 5. However, in a practical embodiment, the maximum number of vanes 21 that can be accommodated around the helix, due to its relatively small diameter at microwave frequencies, is between nine and twelve. As a result, the true anisotropic shell properties are not achieved. Secondly, even though only a few vanes 21 are used, they are extremely difficult to fabricate because they must be thin and must be maintained straight throughout the length of the tube.

In relatively low power traveling wave tubes of the type utilizing a glass envelope, as shown in FIG. 6, anisotropic loading has been obtained by fluting the glass envelope structure 22 with inwardly directed projections 23 serving to support the helix 6 within the fluted glass barrel 22. The gap between the helix and the glass tube reduces the dispersion of the helix. By the proper choice of glass inside and outside diameter to helix diameter, negative dispersion can be achieved. However, the glass envelope structure of FIG. 6 has the disadvantage that the thermal conductivity of the glass is relatively low so that heat is not removed from the helix via the helix support structure. As a consequence, the fluted glass envelope is useful only for relatively low power applications, i.e., cw power outputs less than 10 watts. The glass envelope 22 was surrounded by a thin metallic shield structure 24. The glass served as an anisotropic loading structure between the helix and the shield.

Referring now to FIGS. 9 and 10 there is shown an anisotropic loading structure 26 of the present invention. The anisotropic loading structure 26 comprises a plurality of arcuate sectors of quartz 26 having an array of electrically conductive stripes 27 formed on the inner arcuate surface of the quartz members 26, as by photoetching. In a typical example, 13 line segments 27 are photoetched onto the inner surface of each of the quartz segments 26. The lines 27 are 10 mils wide and the spacing between each line is 10 mils. Therefore, a total of 39 conductive lines 27 are used around the circumference of the helix. The quartz sectors are held to the inside wall of the bore in the envelope 9 via a plurality of metallic clips 28 which grip the sector 26 at

end relieved shoulder portions 29 provided at both ends of the arcuate sectors 26.

The electrically conductive lines 27 are fabricated by sputtering a thin layer of molybdenum onto the inner surface of the quartz sectors 26. The molybdenum coating is then copper plated. The copper plated molybdenum layer is then photoetched to provide the fine line pattern. The anisotropic loading shell structure 26 of FIGS. 9 and 10, as expected, reduces interaction impedance over the operating band and also provides negative dispersion. The amount of negative dispersion that can be obtained for this structure is the same as would be predicted for the ideal anisotropic structure as shown in FIG. 4. In such a structure and for the structure of FIG. 9 an optimum negative dispersion is obtained when the ratio of the diameter of the conductive array to the mean diameter of the helix is approximately 1.34, and preferably within the range of 1.3 to 1.4. Curves 31 and 32 show the loading effect on the velocity synchronism parameter (b) of the array of wires 27. From FIG. 8 it is seen that the velocity synchronism parameter (b) is much more nearly uniform over the octave bandwidth, thereby obtaining uniform gain and efficiency over an octave of bandwidth.

Referring now to FIG. 11 there is shown a second embodiment of the present invention for obtaining anisotropic shell loading of the helix 6. In this case, the anisotropic shell loading comprises three arcuate sectors 34 of alumina ceramic having a dielectric constant of 9.6. These dielectric loading members 34 have no conductive lines printed thereon, as utilized in the embodiment of FIGS. 9 and 10. Therefore, they are more easily fabricated.

The resultant phase velocity for the helix circuit of FIG. 11 is almost constant with frequency over an octave of bandwidth and the interaction impedance is not reduced as much as found in the array of conductive lines on the quartz substrate as employed in the embodiment of FIGS. 9 and 10.

In a preferred embodiment, the dielectric loading sectors have an inside diameter to mean helix diameter ratio falling within the range of 1.3 to 1.4, where the ratio of the inside diameter of the barrel 9 to the mean diameter of the helix 6 falls within the range of 2.0 to 3.0. With the alumina ceramic loading sectors 34, an octave bandwidth was obtained between -4db points.

What is claimed is:

1. In a high power traveling wave tube:
 - a vacuum envelope;
 - means for producing a stream of electrons;
 - a helix type radio frequency slow wave interaction circuit disposed along the path of said stream of electrons in radio frequency energy exchanging relation therewith;
 - a generally cylindrical metallic shell surrounding said interaction circuit;
 - a plurality of dielectric support means circumferentially spaced around said interaction circuit, extending along said circuit and supporting said cir-

cuit from said shell;

anisotropic loading means interposed between said circuit and said shell for making more negative the dispersion characteristic of said circuit;

said anisotropic loading means comprising a plurality of dielectric sectors extending lengthwise of said circuit, circumferentially disposed between said dielectric support means, and abutting said metallic shell;

said dielectric sectors having, a dielectric constant between 9.0 and 10.0, an inner radius from the center of said circuit within the range of 1.3 to 1.4 times the mean radius of said circuit, and an outer radius within 2.0 to 3.0 times said mean radius of said circuit.

2. In a high power traveling wave tube:

means for producing a stream of electrons;

a helix radio frequency slow wave interaction circuit disposed along the path of said stream of electrons in radio frequency energy exchanging relation therewith for cumulative stream-field interaction with the stream to produce a growing radio frequency wave on said circuit;

an evacuated envelope structure having a metallic portion surrounding said interaction circuit;

dielectric support means circumferentially spaced apart around said helix slow wave circuit and extending along said circuit for supporting said helix from said envelope in electrically insulative and heat exchange relation therewith; and

anisotropic loading means surrounding said helix radio frequency interaction circuit and being interposed between said envelope and said helix for adding a negative dispersion effect to the normal positive dispersion characteristic of said helix slow wave circuit, thereby obtaining a less positive or more negative dispersion characteristic, said loading means comprising a plurality of elongated arcuate dielectric support sectors extending along the length of said helix slow wave circuit, said support sectors including an array of elongated longitudinally directed circumferentially spaced electric conductors formed on the inner face thereof facing said helix slow wave circuit, said array of conductors surrounding said helix and being supported from the inner face of said arcuate dielectric sectors.

3. The apparatus of claim 2 wherein said dielectric support sectors which support said array of conductors are of quartz.

4. The apparatus of claim 2 wherein said array of elongated longitudinally directed conductors are axially coextensive with said helix along at least 90% of the length of said helix slow wave circuit.

5. The apparatus of claim 2 wherein the ratio of the inside diameter of said array of electrical conductors to the mean diameter to said helix falls within the range of 1.3 to 1.4.

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