May 31, 1966 J. F. HULL 3,254,262

SLOW-WAVE STRUCTURE FOR CROSSED-FIELD TRAVELLING WAVE TUBE

Original Filed Sept. 28, 1960 2 Sheets-Sheet 1

Fig. 1

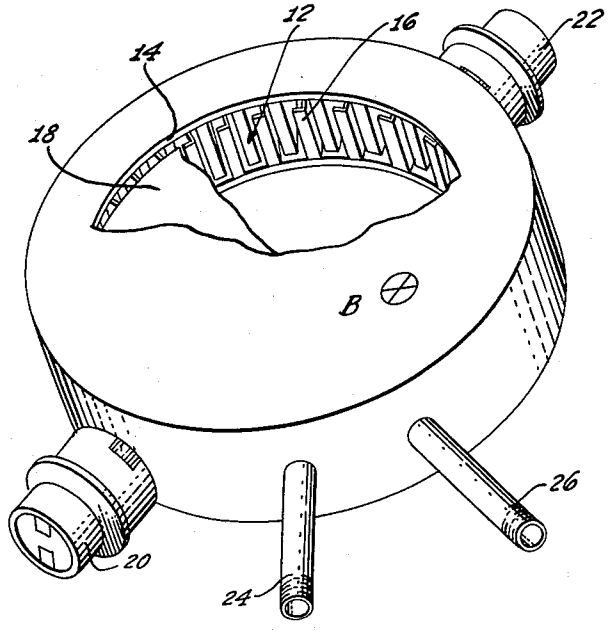


Fig. 2

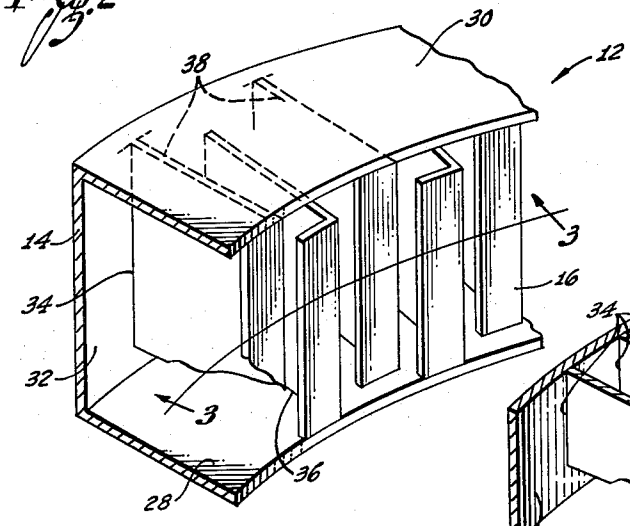
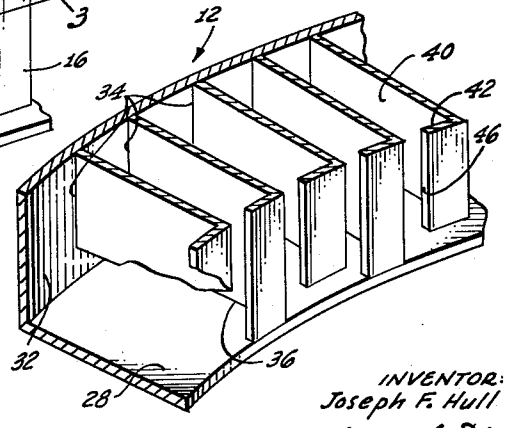


Fig. 3



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Fig. 4

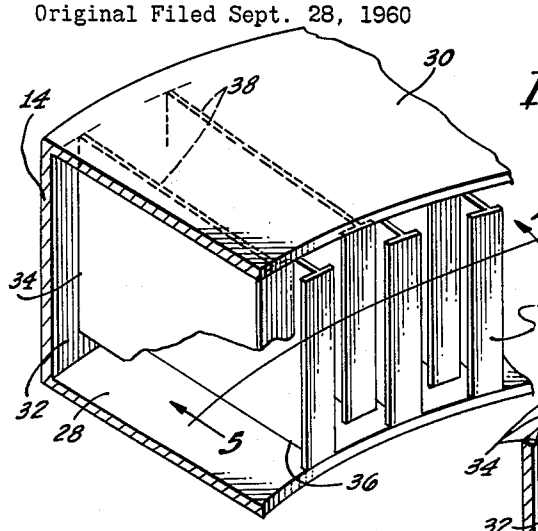


Fig. 5

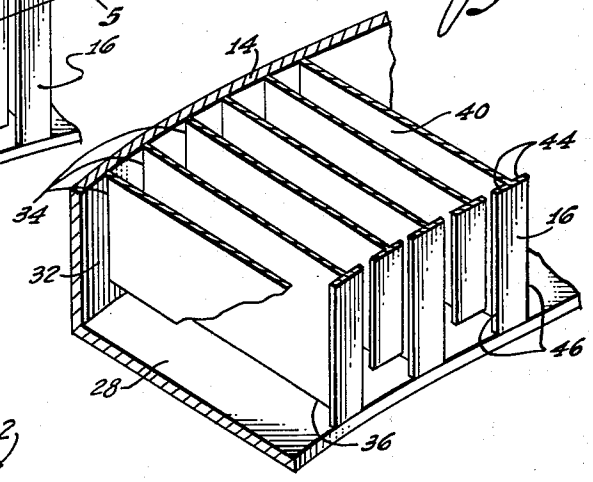


Fig. 6

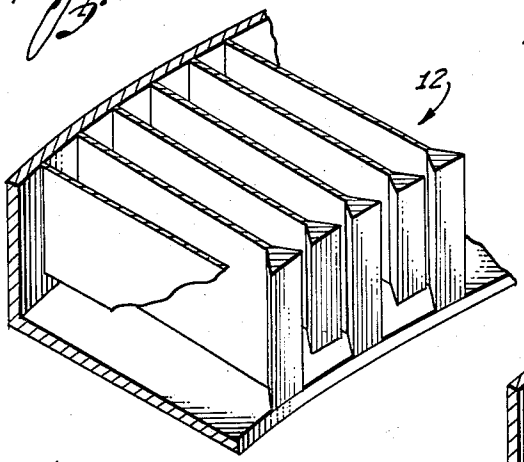


Fig. 7

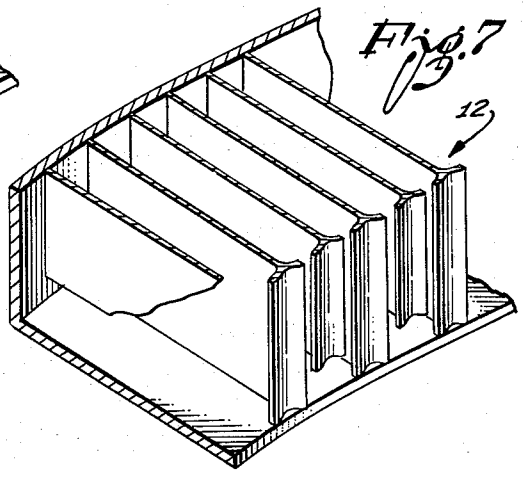
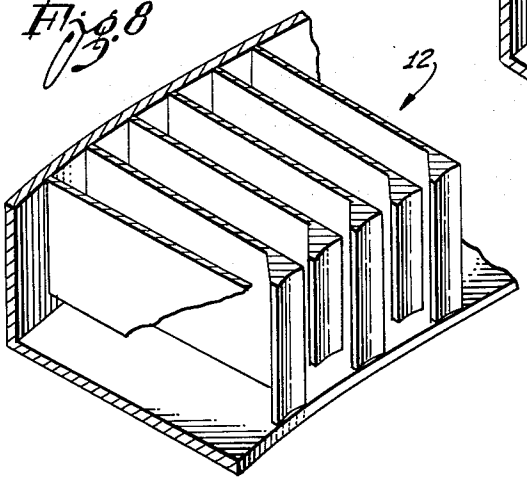


Fig. 8



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3,254,262

SLOW-WAVE STRUCTURE FOR CROSSED-FIELD TRAVELLING WAVE TUBE

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Continuation of abandoned application Ser. No. 59,074, Sept. 28, 1960. This application Nov. 12, 1963, Ser. No. 325,202

4 Claims. (Cl. 315—3.5)

This application is a continuation of my application Serial No. 59,074, filed September 28, 1960, now abandoned.

The present invention relates to a slow-wave structure for crossed field travelling wave devices and more particularly to an improved slow-wave structure for crossed field travelling wave tubes adapted for use in either a forward or backward traveling wave amplifier or oscillator device.

In the prior art, crossed field amplifier or oscillator devices generally have included a slow-wave structure along which a microwave frequency electromagnetic wave is propagated in interaction relationship with an electron beam. The slow-wave structures for such devices, which may be rectilinear or curved, usually have a geometrically periodic structure, which includes elements such as vanes forming cavities, fingers of an interdigital form, rods of a ladder line, or the like. In operation, such slow-wave structures have been employed in travelling wave devices to amplify an input signal when the direction of the group velocity of an associated electromagnetic wave is in the same direction as the electron beam, whereas, when the group velocity is in the opposite direction of the electron beam, voltage tunable amplification or oscillation is generated within such a travelling wave device.

Although the prior art slow-wave structures have been found to perform reasonably well at low power levels, all of the known structures have at least one of several serious disadvantages attendant their use at higher power levels. Firstly, the configuration and disposition of some structural elements provide a low interaction impedance causing the device to be relatively inefficient in exchanging energy with the associated electron beam, thus causing low gain and low efficiency. Secondly, the configuration, size and surface area of other structure's elements, such as the typical interdigital finger, for example, are incapable of dissipating large amounts of heat when exposed to high temperatures during high average power operation. Thirdly, some devices have too narrow a band width for some desired applications. Finally, in some slow-wave structures, the size and shape of the structural elements which determine the mechanical strength of the structural elements are insufficient to enable them to withstand distortions or derangements during the process of fabrication or when exposed to high temperatures. This final disadvantage is particularly prevalent in relatively high frequency devices in which the small dimensions required result in extremely fragile elements.

The desirability of high gain, broad band width and mechanical stability is obvious, and the necessity for these characteristics is readily appreciated. However, it may be helpful to consider the concept of interaction impedance in order to understand why a high impedance is necessary for maximum interaction with the electron beam.

An electromagnetic wave travelling in a periodic wave guide structure such as the slow wave structure of a travelling wave electron discharge device may be thought to consist of many space harmonic waves of the same frequency but of differing velocities, with some of these space harmonic waves being forward waves, which is to say waves travelling in the same direction as the associated electron beam, and others of these space harmonic waves being backward waves. Such devices are designed so that the electron beam interacts with only a chosen one of these space harmonic waves, with the chosen wave being a forward wave in the case of devices such as forward wave amplifiers and being a backward wave in the case of devices such as backward wave oscillators. In either case the device is designed such that the velocity of the electron beam is substantially equal to the phase velocity of the chosen space harmonic wave.

The interaction impedance of the structure may be defined by the following equation:

$$Z_i = \frac{E_s^2}{z\beta_s^2 P}$$

where Z_i is the interaction impedance, E_s is the maximum electric field intensity of the chosen space harmonic wave, P is the power being propagated and β_s is from the familiar wave equation:

$$E = E_0 e^{j(\omega t - \beta z)}$$

for the chosen space harmonic wave.

Thus, for a given power flow in a slow wave structure, it is readily apparent that the electric field intensity of the chosen space harmonic wave is strongest in the device having the highest impedance. Since the individual electrons in the beam interact with the electric field component of the chosen space harmonic wave, it is desirable to provide such electric fields in order that the beam may interact to the greatest possible extent with the wave to provide maximum gain of the wave and power transfer from the beam to the wave. Thus, a slow wave structure which has the highest interaction impedance allows the maximum gain per unit length in the wave being propagated on the slow wave structure and the greatest power transfer per unit length from the beam to the wave.

The interdigital delay line is widely used as a slow wave structure in crossed field devices, especially in relatively low power backward wave oscillators. Such a slow wave structure has a relatively high electrical impedance and thus provides excellent coupling from the beam to the wave. However, at high frequencies, the dimensions of the fingers in the line become so small that the fingers become mechanically unstable and also have very poor heat conduction characteristics. The fingers thus tend to buckle or melt when electrons from the beam inpinge upon them.

The helix is another widely used slow wave structure in travelling wave tubes. It has high electrical impedance and relatively broad band width. However, at high frequencies the required dimensions of the helix become so small that the helix is difficult to support, becomes mechanically unstable and can dissipate very little power.

There is another class of slow wave structure which may be termed a split folded wave guide structure. A device embodying such a structure is disclosed in my United States Patent 3,123,735. This structure may be thought of as a rectangular wave guide split in the middle with half of this wave guide folded in a serpentine manner to form a slow wave structure, with the electron beam being projected along the serpentine shaped opening in the structure for interaction with any electromagnetic wave propagating in the structure. The structure itself appears as a U-shaped channel having first alternate vanes attached to one side wall and the base of the channel and having the other alternate vanes attached to the other side wall and the base of the channel. Such a slow wave structure has a relatively broad band width and relatively high mechanical stability. It

is especially good at dissipating any heat generated on the structure by impinging electrons. However, as is discussed in the above mentioned co-pending application, the electrical impedance of the device is relatively low, thus causing relatively low gain and and low efficiency.

It is, therefore, an object of this invention to provide an improved slow wave structure for travelling wave tubes.

It is another object of this invention to provide an improved slow wave structure for a crossed field travelling wave tube which has high electrical impedance.

It is yet another object of the present invention to provide an improved slow wave structure for a crossed field travelling wave tube which has a broad band width.

It is yet another object of the present invention to provide an improved slow wave structure for a crossed field travelling wave tube which has high mechanical stability and heat dissipation characteristics.

Briefly stated, and in accordance with one embodiment of the present invention, a slow wave structure for a crossed field travelling wave tube is provided which includes a split folded wave guide arrangement such as was previously described. The edge adjacent the interaction region of each of the vanes is enlarged so as to decrease the distance between the edges of the adjacent vanes. The structure thus appears as a folded rectangular wave guide having opposed broad and narrow walls forming an undulating passage for the propagation of an electromagnetic wave, with one of the narrow walls having a continuous slot formed therein following the path of the undulating passage, with the width of this slot being smaller than the distance between the opposing broad walls of the wave guide.

For a complete understanding of the invention, together with other objects and advantages thereof, reference may be had to the accompanying drawings, in which:

FIGURE 1 is an isometric view, partly in section, of a crossed field travelling wave device illustrating an improved slow wave structure in accordance with the present invention;

FIGURE 2 is an isometric view, partly in section, of a fragmentary portion of the slow wave structure in accordance with the invention, which is employed in the device of FIGURE 1;

FIGURE 3 is an isometric view, partly in section, of the fragmentary portion of the slow wave structure shown in FIGURE 2 taken along the line 3—3;

FIGURE 4 is an isometric view, partly in section, of a fragmentary portion of another embodiment of the slow wave structure in accordance with the invention which may be employed in the device in FIGURE 1;

FIGURE 5 is an isometric view, partly in section, of the fragmentary portion of the slow wave structure shown in FIGURE 4 taken along line 5—5; and

FIGURES 6, 7, and 8 are fragmentary views, partly in section, of portions of several modifications of the slow wave structures shown in FIGURES 3 and 5.

With reference now to the drawings, wherein the same reference characters designate like or corresponding parts throughout the several views, there is shown in FIGURE 1 an isometric view of a crossed field travelling wave device embodying a modified split folded wave guide slow wave structure in accordance with one embodiment of the invention, for increasing the interaction impedance of the slow wave structure to provide high interaction efficiency between an electron beam in coupled relationship with the slow wave structure while simultaneously providing increased heat conducting capabilities for higher average power operation. The device of FIGURE 1 may be either a forward wave amplifier or a backward wave oscillator.

As shown in FIGURE 1, the device includes a slow wave structure generally designated **12** of a circular configuration having a body **14** with a U-shaped radial cross-section, and, in accordance with one embodiment

of the present invention, a plurality of regularly spaced vanes **16** having an L-shaped cross-section, an associated sole electrode **18** disposed concentrically with the slow wave structure, and a pair of input and output couplers **20** and **22**, respectively, for communicating radio frequency energy into and out of the device. In addition, the device also includes an electron gun, which is not shown, disposed at one end of the slow wave structure **12** for producing and directing an electron beam along a predetermined interaction path between sole **18** and the slow wave structure **12** and a pair of connections designated **24** and **26** which function respectively as an inlet and outlet for an associated internal channel for cooling the slow wave structure.

It should be noted here that, although not shown, in accordance with the embodiment of the invention shown in FIGURE 1, any suitable means, such as a permanent magnet or electromagnet, may be provided for supplying an associated transverse magnetic field needed for operation of the device. In FIGURE 1, the magnetic field is indicated by the encircled X at B normal to the plane of the flat surface of the device. The magnetic field provides, in combination with a transverse D.C. field between sole **18** and the slow wave structure **12**, means for fousing the electrons of the electron beam to transfer energy from the beam to the slow wave circuit. However, the general theory of operation of such crossed field devices is well known to those skilled in the art and will not be further discussed herein.

Referring now to the enlarged fragmentary views of FIGURES 2 and 3, the slow wave structure **12** is shown to comprise channel structure **14** having a U-shaped configuration including first and second orthogonal side walls, designated **28** and **30** respectively, separated by a common backwall section or base **32** affixed therebetween. Disposed within the U-shaped structure is a plurality of vanes **16** with an L-shaped cross-section, each of which is affixed at its remote end **34** to backwall **32**. In addition, one side of first alternate vanes **36** is connected to first parallel section or side wall **28** and the other side of the remaining alternate vanes **38** is connected to the other side wall **30**. The slow wave structure may thus be viewed as a split folded wave guide which comprises a member in the form of a portion of the toroid having a U-shaped cross-sectional configuration in which the side walls are two planar annular members **28** and **30** separated by a cylindrical backwall **32** and a plurality of planar vanes **40** each connected at one end to said backwall at a point generally designated **34** while each of the opposite ends is connected to a planar conductive vane tip member **42**, the plane of each of said vane tip members being substantially orthogonal to the plane of its associated vane and the width of said tip member being less than the distance separating adjacent vanes. Alternate vanes are connected to one of the annular members and spaced from the other, the remaining vanes are connected to the other annular member and spaced from the one member.

Referring now to FIGURE 3, it is seen that each vane includes a planar section **40** perpendicular to the side walls of the channel structure **14** and to the direction of electron beam travel. Each vane also includes a smaller section **42** which is perpendicular to the planar sections **40** and parallel to the back wall **32** of the channel and to the direction of electron beam travel. It is further seen that the spacing between the adjacent planar surfaces **40** is considerably greater than the spacing between the adjacent edges of the adjacent sections **42**. In practice, the spacing between the edges of surfaces **42** may be one-half or less the spacing between adjacent planar surfaces **40**.

Consider now the superior electrical characteristics of such a line as has been described as compared to a split folded wave guide structure without the members **42** attached to the edges. The dominant mode for an electromagnetic wave in a rectangular electrical wave

guide structure is the TE_{10} mode, and this mode is the dominant mode of an electromagnetic wave propagating in the split folded wave guide, whether it has the members **42** attached or not. Such a mode has an electrical field intensity of zero adjacent the back wall **32** of channel **14** and has its maximum field intensity along the serpentine groove adjacent the interaction region where the wave interacts with the electron beam. The provision of members **42** along the outer edges of the vanes, in decreasing the spacing between adjacent vanes to one-half or less the previous spacing, provides an electrical field intensity in this region of twice or greater the field intensity which would occur in a conventional split folded wave guide. Thus, for a given power transfer down the slow wave structure, the electric field maximum in the device of the present invention is considerably higher than that in a conventional split folded wave guide and the device of the present invention thus has a considerably higher interaction impedance.

The higher electrical field intensity, and thus the higher interaction impedance, provides for much tighter coupling between the electron beam and the wave propagating in the slow wave structure which, in turn, provides greater gain per unit length and higher efficiency. This may readily be seen when one considers the higher field intensities caused by the present invention are immediately adjacent the interaction region and that any electron beam travelling in the interaction region sees a much higher electrical field component of the chosen space harmonic of the wave with which to interact.

The device is also an extremely broad band width slow wave structure. For example, two constructed structures have exhibited bandwidths of 2400–3600 mc. and 8000–11,000 mc.

In addition to the superior electrical characteristics of the slow wave structure of the present invention, which are considered to be the primary advantages of the invention, the structure also has inherently superior mechanical characteristics. Thus, the provision of member **42** braces each of the vanes and greatly strengthens the vanes to provide ease of fabrication and to provide a more rugged tube capable of withstanding higher mechanical shock. Also, member **42** provides a larger surface area for electrons which are collected by the slow wave structure to impinge upon. This prevents extreme localized heating on the tips of the vanes caused by the impinging electrons. This is considered to be an extremely important characteristic since in tubes of this kind usually half or more of the electron beam is collected on the slow wave structure and the kinetic energy of the impinging electrons must be converted to heat and dissipated in the vane tip regions where the beam impinges. The rigidity provided by member **42** is of additional utility at this time to help prevent buckling of the vanes which might otherwise be caused by the heating in the vane tip region.

Referring still to FIGURE 3, it is noted that the planar section **40** of each vane is of relatively large surface area extending from each relatively smaller vane tip member **42** disposed within the device adjacent the interaction region. Each section **40** surface is a relatively massive heat conducting path from member **42** to the back wall **32**, through which path heat may be substantially removed from surface **42** by conduction. Heat may be removed from backwall **32** by any suitable associated cooling means (not shown) which may be in thermal contact therewith. In addition to being removed through surfaces **40** to the back wall **32**, heat is also removed through the side walls **28** and **30** of the U-shaped structure to which the alternate vanes are affixed.

Referring now to FIGURES 4 and 5, there is shown two fragmentary views of a slow wave structure **12** similar to that shown in FIGURES 2 and 3, except that vanes **16** have a T-shaped cross-section having substantially the same mechanical and electrical characteristics as those of structure **12** in FIGURE 1. However, it should be noted that there are applications in which it is more desirable to employ the T-shaped structure because of its symmetry, since the mechanical distortion of a symmetrical structure under conditions of RF and electron exposure is less than that of the asymmetrical structure. Furthermore, the electrical design of an RF matching section between the slow wave structure and an external wave guide is the same for the output as for the input in the symmetrical structure.

Referring more specifically to FIGURES 4 and 5, the small section of the T-shaped vane generally designated **44** is disposed with equal portions of the section on either side of section **40**. Assuming that like or corresponding parts shown in FIGURES 2 and 4 have the same dimensions, the structure has substantially the same electrical characteristics, except that the impedance of the structure of FIGURES 4 and 5 is symmetrical when viewed from the opposing ends. It is to be expressly understood, however, that there is at least one mechanical difference between the two structures which will be described in more detail.

Consider now the manner in which heat is conducted from vanes **16** to main body structure **14**. Referring again to FIGURE 3, it can be seen that the combination of sections **42** and **40** is one continuous element having a non-planar cross-section in the form of an L. It is apparent from the figure that when the electrons of an associated electron beam, which is not shown, impinge upon section **42**, generating heat therein, an edge **46** heats up fastest since it is remote from the junction between sections **42** and **40** where the largest concentration of metal or the heat sink of the vane occurs. In the process of conducting heat, the path of heat flow is from edge **46** through section **42** through the junction into section **40** and thence to the back wall and orthogonal walls along a relatively massive path as defined by the length of section **40**.

Referring again to FIGURE 5, section **44** has two edges generally designated **46** which become hotter than the middle area of section **44**, as stated hereinabove, because there is less metal concentrated at the edges to be heated up than there is at the junction between sections **40** and **44**. In contrast to number of heat conducting paths which exist in the vanes shown in FIGURE 3, the vane shown in FIGURE 5 has two heat conducting paths, so that during the heat conducting process the heat which is generated in the section **44** flows from both of the edges of vane section **44** toward the junction between sections **40** and **46**. In view of the foregoing discussion, it becomes apparent that the T-shaped vanes of FIGURE 5 provide better heat conduction characteristics than the L-shaped vanes. This can be demonstrated by the comparison of operational data for separate devices employing slow wave structures having different vane configuration.

It should be noted at this point that it may be desirable to use one configuration in preference to the other, depending upon the particular electrical and mechanical requirements of the device in which the slow wave structure is to be employed. For example, it may be desirable to use the T-shaped vane where it is necessary to have a symmetrical impedance characteristic, or stated differently, where the impedance of the structure is the same when measured from either end of the structure. Conversely, it may not be necessary to have the same impedances at opposite ends, whereupon the L-shaped vane could be employed.

FIGURES 6, 7, and 8 show views similar to FIGURES 3 and 5 of additional embodiments of the invention. The embodiment of FIGURE 6 is considered to be an especially advantageous embodiment of the invention. As shown therein, each vane has a "nose" attached to the end facing the interaction region, with this nose being substantially in the shape of a triangle having one point

affixed to the vane and having the base opposite this point parallel to the direction of beam travel. This embodiment, together with the embodiments of FIGURES 7 and 8, also provides the above discussed advantages of high electrical impedance, thereby promoting high gain and efficiency, broad band width, mechanical stability and good heat dissipation characteristics.

While the invention is thus disclosed and several embodiments described, the invention is not limited to those shown embodiments. Instead, many modifications will occur to those skilled in the art which lie within the scope of the invention. Accordingly, it is intended that the invention be limited in scope only by the impending claims.

What is claimed is:

1. In a crossed field travelling wave tube having a slow-wave structure adapted for use at microwave frequencies which introduces a delay in the phase propagation of a travelling electromagnetic energy wave over a relatively wide frequency range, the combination comprising: a high gain, high impedance slow-wave structure in the form of a channel having a U-shaped cross-sectional configuration formed by two planar members separated by a backwall; means to form a magnetic field parallel to said backwall, a plurality of planar vanes each connected to the backwall, alternate vanes being connected to one of the planar members and spaced from the other, the remaining vanes being connected to said other planar member and spaced from said one member; a sole member spaced from said slow-wave structure and forming an interaction space therebetween to provide an electric field perpendicular to said magnetic field; and a plurality of planar conductive vane tip members corresponding to and associated with said plurality of vanes, each of said vane tip members being connected to the end of the corresponding vane contiguous with the interaction space such that said vane provides increased conduction of heat away from the respective vane tip member; the plane of each of said vane tip members being substantially orthognal to the plane of its associated vane and the width of said tip members being less than the distance separating adjacent vanes, said vanes forming a plurality of closely spaced interaction gaps between adjacent vanes for supporting high intensity radio frequency electric fields associated with said traveling electromagnetic energy wave.

2. A slow-wave structure adapted for use in a crossed-field travelling wave tube to increase the power handling capabilities and ruggedness of the tube without significant sacrifice in efficiency and wide band frequency characteristics, the combination comprising: a channel structure having a U-shaped configuration, said structure includes first and second parallel walls separated by a common backwall formed therebetween, and a plurality of L-shaped vanes being formed by a short section at right angles with a longer section, each affixed at one end thereof to said backwall and one side of alternate vanes being connected to one of the parallel walls, the other side of interstitial vanes being connected to the other of said parallel walls, said vanes thereby defining a serpentine wave path which includes a plurality of closely spaced interaction gaps between adjacent vanes for supporting high intensity radio frequency electric fields associated with said electromagnetic wave while simultaneously providing high heat conducting characteristics.

3. A slow-wave structure in the form of a modified split-folded waveguide adapted for use in a travelling wave tube having crossed electric and magnetic fields, which permits an associated electron beam to interact with an electromagnetic wave propagating therein with maximum efficiency while simultaneously providing high heat conducting characteristics, the combination comprising: a channel structure having a U-shaped configuration, said structure includes a pair of parallel walls separated by a common wall formed therebetween, and plurality of T-shaped vanes being formed by a long section bisecting perpendicularly an associated shorted section each connected at one end thereof to said backwall and one side of alternate vanes being connected to one of said parallel walls, the other side of the interstitial vanes being connected to the other of said parallel walls, said vanes thereby defining a serpentine wave path which includes a plurality of closely spaced interaction gaps between adjacent vanes for supporting high intensity radio frequency electric fields associated with said wave, while simultaneously increasing the power handling capabilities and ruggedness of the tube without significant sacrifice in efficiency and broadband frequency characteristics.

4. In a travelling wave tube adapted to produce oscillations over a relatively wide frequency range, having a slow-wave structure in coupled relationship with an electron beam which interacts with a backward or a forward space harmonic of an electromagnetic wave propagating in said slow-wave structure, said slow-wave structure comprising: a U-shaped structure having a backwall and two orthogonal walls connected thereto, and a plurality of vanes whose configuration is non-planar, each affixed at one end thereof to said backwall and one side of alternate vanes being connected to one of the orthognal walls, the other side of the remaining vanes being connected to the other of said orthogonal walls, said vanes providing for the dissipation of heat concentrations and thereby defining a serpentine wave path which includes a plurality of closely spaced interaction gaps between adjacent vanes for supporting high intensity radio frequency electric fields associated with said electromagnetic wave.

References Cited by the Examiner

UNITED STATES PATENTS

2,768,328	10/1956	Pierce	315—39.3
2,888,595	5/1959	Warmeche	315—3.5
2,888,598	5/1959	Palluel	315—316
2,916,656	12/1959	Moats	315—3.5
3,046,443	7/1962	Dench	315—39.3
3,089,974	5/1963	Hergenrother	315—316

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