United States Patent [19]

Scott

[11] **3,809,949**

[45] **May 7, 1974**

[54] **APPARATUS FOR INCREASING RF CONVERSION EFFICIENCY OF A TRAVELING WAVE TUBE**

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[73] Assignee: **Varian Associates,** Palo Alto, Calif.

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[52] **U.S. Cl.** **315/3.5,** 315/3.6, 315/39.3

[51] **Int. Cl.** **H01j 25/34**

[58] **Field of Search** 315/3.5, 3.6, 39.3

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Assistant Examiner—Saxfield Chatmon, Jr.
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[57] **ABSTRACT**

The RF conversion efficiency of a vane loaded helix derived slow wave circuit, such as a ring and bar, meander line, double meander line, helix, cross wound helix, double ring and bar or a ladder line circuit, is increased while maintaining broad band operation; in a first embodiment, by increasing the degree of penetration of the vanes into the slow wave circuit at the output end of the tube for introducing a frequency dependent velocity taper and, in a second embodiment, by electrically isolating the aforementioned loading vanes for d.c. potential at the output end of the tube and applying a higher beam voltage to these circuit loading vanes.

12 Claims, 10 Drawing Figures

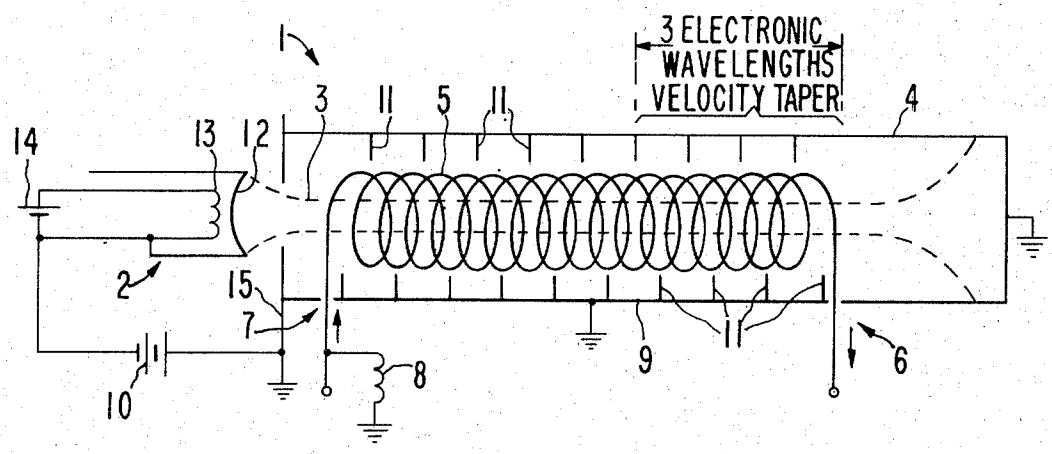


FIG.1

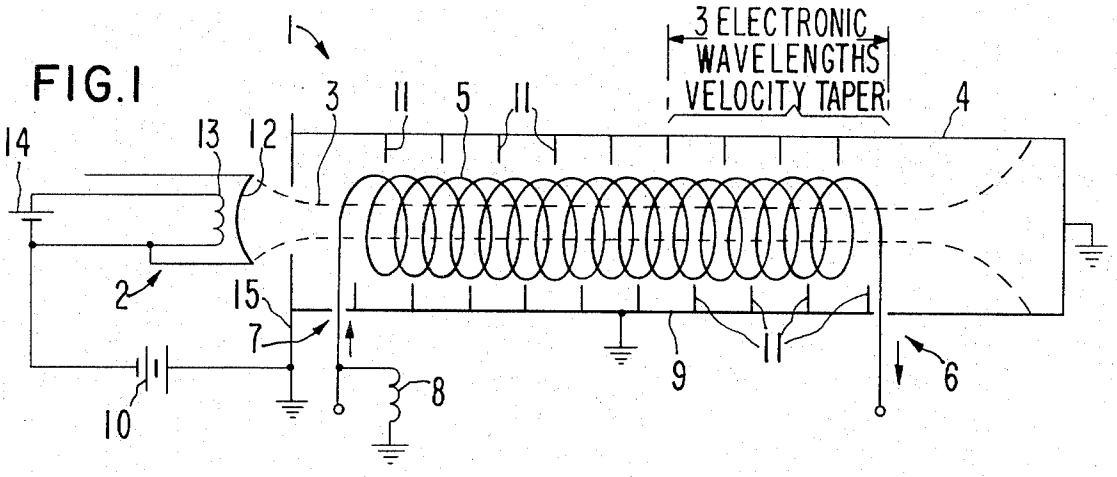


FIG.2

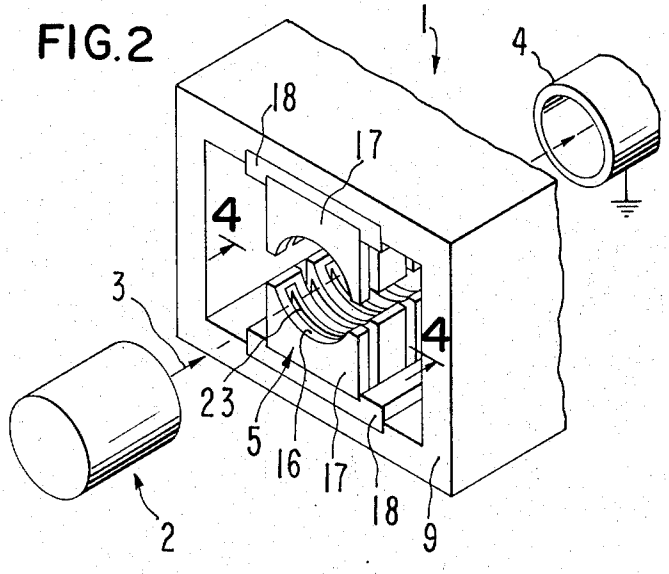


FIG.3

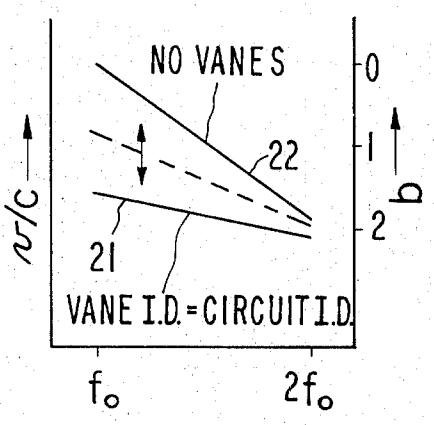


FIG.4

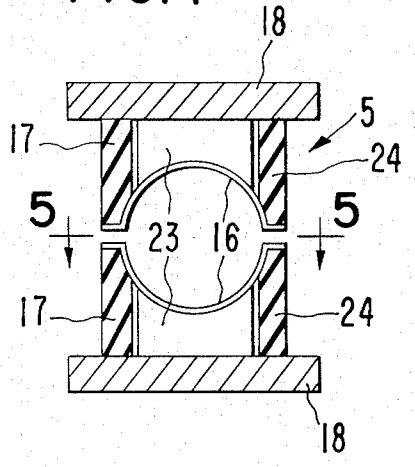


FIG.5

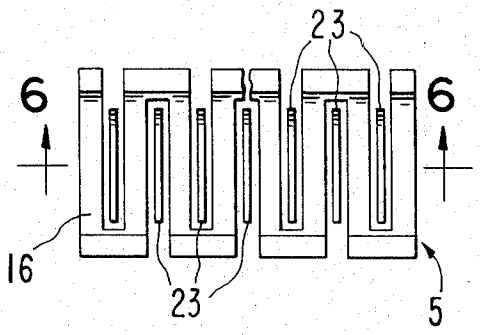


FIG. 6

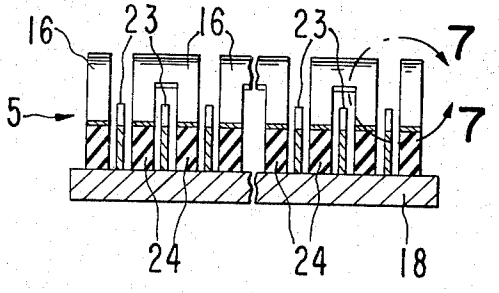


FIG. 7

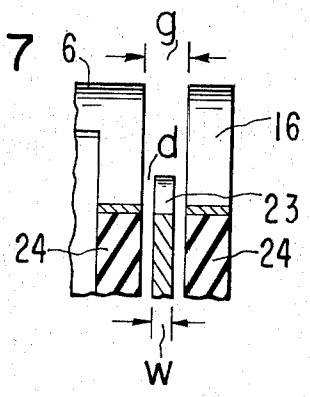
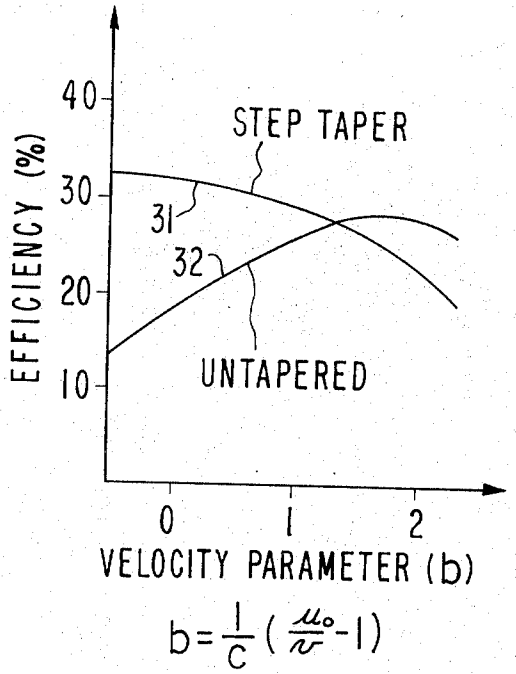


FIG. 8



$$b = \frac{1}{C}\left(\frac{\mu_0}{v} - 1\right)$$

FIG. 9

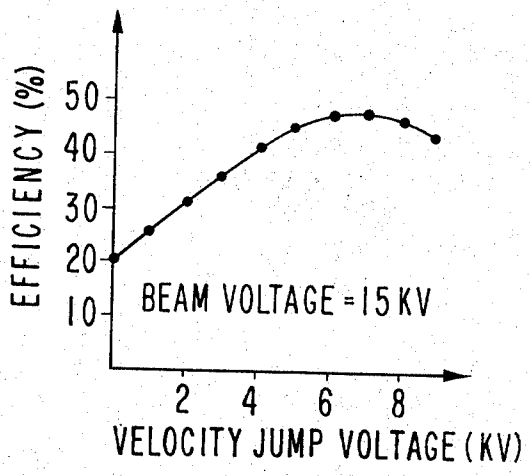
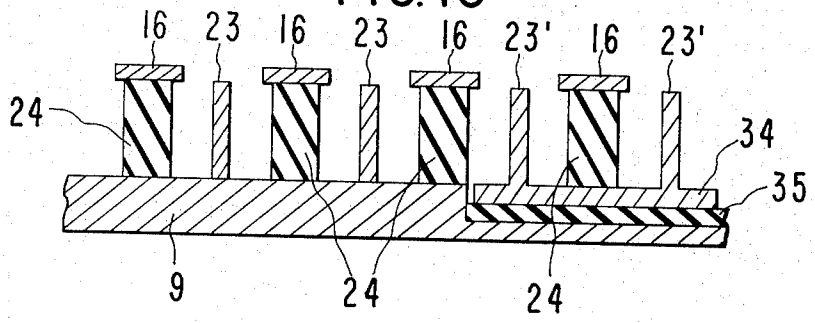


FIG. 10



APPARATUS FOR INCREASING RF CONVERSION EFFICIENCY OF A TRAVELING WAVE TUBE

BACKGROUND OF THE INVENTION

The present invention relates in general to slow wave tubes and more particularly to improved method and apparatus for increasing the RF conversion efficiency of such tubes.

DESCRIPTION OF THE PRIOR ART

Heretofore, the power output and bandwidth of helix derived slow wave tubes has been substantially increased by employing a ceramic comb support for a ring and bar helix derived circuit. Such circuits typically provide bandwidths from the size provided by standard waveguides to octave sizes, with an order of magnitude increase in average power capability over rod mounted helix slow wave circuits. A prior art slow wave tube employing a comb supported ring and bar circuit is disclosed and claimed in U.S. Pat. Nos: 3,505,730, issued Apr. 14, 1970; 3,508,108, issued Apr. 21, 1970; and in U.S. Pat. application Ser. No. 8,793, filed Feb. 5, 1970, all of which are assigned to the same assignee as the present invention. In such a slow wave circuit, heat is conducted directly from the circuit through the ceramic comb to the envelope of the tube, rather than being conducted around the helical wire of the circuit and then through ceramic support rods to the envelope.

All high power traveling wave tubes are required to have relatively high RF conversion efficiency or else excessive power will be intercepted and dissipated in the slow wave circuit.

Heretofore, phase velocity tapering of the slow wave circuit of a traveling wave tube has been proposed to enhance RF conversion efficiency. In the typical traveling wave tube, as the beam approaches the output end of the circuit the mean velocity of the beam has been decreased due to the loss of energy from the beam to the slow wave circuit. Accordingly, the beam begins to fall out of synchronism with the wave on the circuit, resulting in a loss of conversion efficiency.

In the prior art, the pitch of the helix or helix derived slow wave circuit is normally decreased near the output end of the circuit to produce a reduction in the phase velocity of the signal wave energy on the circuit to more nearly maintain synchronism with the beam to improve the RF conversion efficiency. The problem with this technique is that the slow wave circuit is dispersive, i.e. the wave energy on the circuit at the low frequency end of the passband has a much higher phase velocity than the wave energy on the circuit at the high frequency end of the passband. However, changing the pitch of the circuit produces a uniform reduction in the phase velocity of the wave energy on the circuit. Thus, reducing the pitch of the slow wave circuit, while improving the efficiency of the tube at the low frequency end of the passband, causes the wave energy at the high frequency end to fall too far out of synchronism with the beam, resulting in narrowing of the passband of the tube.

As a consequence, it would be desirable to provide a frequency dependent phase velocity circuit that would produce a greater shift of the wave energy at the low frequency end of the band than at a high frequency end of the band, whereby the RF conversion efficiency

of the tube is increased without encountering a reduction in the width of the operating passband of the tube.

It has also been proposed in the prior art that the conversion efficiency of a traveling wave tube could be increased by providing an increase jump in the velocity of the electron beam at the output end of the circuit. More particularly, it has been suggested that a length of the output circuit could be severed for d.c. potential from the first part of the slow wave circuit and a higher anode potential applied to the output end of the slow wave circuit for producing a step like increase in the velocity of the electron beam at the output end of the circuit, thereby counteracting the tendency of the electron beam to be slowed down at the output end of the circuit.

The problem with this latter technique is that it requires severing of the slow wave circuit to allow an independent d.c. potential to be applied to the output end of the circuit relative to the input end of the circuit. This severing of the circuit produces undesired reflections of wave energy and is generally difficult to achieve in practice.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of improved apparatus for increasing RF conversion efficiency of a traveling wave tube.

In one feature of the present invention, periodic circuit loading members project into the region between adjacent periodic elements of the helix derived slow wave circuit for decreasing the dispersiveness of the circuit. Such loading elements penetrate further into the slow wave circuit at the output end of the circuit for introducing a frequency dependent loading which preferentially lowers the phase velocity of the low frequency end of the operating band, thereby improving the RF conversion efficiency without substantially decreasing the bandwidth of the tube.

In another feature of the present invention, the periodic loading elements comprise conductive vane members projecting into the spaces between adjacent ring portions of the ring and bar circuit with the degree of penetration of such loading vanes increasing toward the output end of the tube.

In another feature of the present invention, periodic loading members project inwardly of the slow wave circuit in between adjacent periodic elements thereof at the output end of the circuit. The periodic loading elements are isolated for d.c. potential from the slow wave circuit and from a surrounding microwave ground plane structure to permit a d.c. potential to be applied to such loading members relative to the slow wave circuit and to the surrounding microwave ground plane for increasing the velocity of the beam near the output end of the circuit for increasing the RF conversion efficiency.

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 schematic longitudinal sectional view, partly in line diagram form, of a traveling wave tube incorporating features of the present invention,

FIG. 2 is a perspective foreshortened view of a microwave tube of the type schematically shown in FIG. 1,

FIG. 3 is a plot of normalized circuit phase velocity and velocity synchronism parameter (b) versus frequency for a slow wave circuit with and without loading vanes,

FIG. 4 is a sectional view of the structure of FIG. 2 taken along line 4—4 in the direction of the arrows,

FIG. 5 is a view of the structure of FIG. 4 taken along line 5—5 in the direction of the arrows,

FIG. 6 is a view of the structure of FIG. 5 taken along line 6—6 in the direction of the arrows,

FIG. 7 is an enlarged detail view of a portion of the structure of FIG. 6 delineated by line 7—7,

FIG. 8 is a plot of efficiency in percent versus velocity synchronism parameter (b) for two slow wave tubes, one utilizing a velocity untapered slow wave circuit and a second using a step velocity tapered slow wave circuit,

FIG. 9 is a plot of efficiency versus velocity jump voltage for a slow wave circuit wherein the beam voltage is increased at the output end of the tube, and

FIG. 10 is a longitudinal sectional view of a portion of a vane loaded helix derived slow wave circuit wherein increased beam voltage is applied to the loading members at the output end of the circuit.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 there is shown a microwave traveling wave tube 1 incorporating features of the present invention. The tube 1 includes an electron gun assembly 2 for forming and projecting a beam of electrons 3 over an elongated beam path to a beam collector structure 4 disposed at the terminal end of the beam for collecting and dissipating the energy of the beam. A helix derived slow wave circuit 5 is disposed intermediate the gun 2 and the collector 4 along the beam path 3 for cumulative electromagnetic interaction with the beam to produce output microwave energy which is extracted from the circuit 5 via a conventional output coupling 6.

Microwave energy is applied to the upstream end of the slow wave circuit via the intermediary of an input coupler 7. The helix derived slow wave circuit 5 is typically operated at ground or anode potential and is isolated from ground for microwave energy via the intermediary of a suitable RF choke 8. The slow wave circuit 5 is surrounded by an electrically conductive barrel structure 9 forming a microwave ground plane and the vacuum envelope for the tube.

Electrically conductive periodic loading vanes 11 project inwardly from the envelope 9 in between adjacent periodic elements, as of adjacent turns, of the helix derived slow wave circuit 5 to decrease the dispersiveness of the slow wave circuit 5. Such a vane loaded helix derived slow wave circuit and tube using same is disclosed and claimed in U.S. Pat. No. 3,654,509, issued Apr. 4, 1972, and assigned to the same assignee as the present invention.

The electron gun assembly 2 includes a thermionic cathode emitter 12 heated to thermionic cathode emission temperature via the intermediary of a filamentary cathode heater 13 supplied with power from a power supply 14. The thermionic cathode emitter 12 includes a spherically concave cathode emitter surface coaxially aligned with a centrally apertured anode 15 supplied with anode potential, as of +15 kv, relative to the thermionic cathode emitter 12 via an anode supply 16.

Referring now to FIGS. 2–6, the vane loaded helix derived slow wave circuit of the type shown in FIG. 1 will be described in greater detail. More particularly, the slow wave circuit 5 comprises a topologically equivalent ring-and bar, helix-derived microwave circuit including a pair of opposed meander line portions 16 disposed in transverse registration upon the concave trough surface of a pair of serpentine-shaped ceramic insulator structures 17, as of alumina or beryllia ceramic. In a preferred embodiment, the ring-and-bar slow wave circuit portions 16 are conveniently bonded to the dielectric support 17 by sputter depositing a relatively thin layer of molybdenum or tungsten to a thickness of 400 to 10,000 angstroms.

The sputter-deposited metal forms a tightly adhering layer. Rhodium is then plated over the base layer to a thickness, as of 0.0002–0.0003 inch. The serpentine-shaped dielectric supports 17 are each brazed to a plate 18 having a coefficient of thermal expansion matching that of the ceramic supports. Such a suitable material includes Elkonite (copper inpregnated tungsten matrix). The plates 18 are in turn brazed into a copper barrel 9 of rectangular cross section forming the vacuum envelope of the tube.

An array of electrically conductive vanes 23, as of molybdenum, are interposed in the space between adjacent vane portions 24 of the dielectric circuit support structure 17. The conductive vanes 23 are bonded, as by brazing, to the plate portion 18 of the barrel structure 9. The inner tips of the conductive vanes 23 have a concave curve conforming to the outer peripheral curvature of the microwave circuit 16.

The conductive vanes 23 are axially spaced in the direction of the beam from the adjacent dielectric vanes 24 by a small gap *d* and preferably extend as close as possible to the outer peripheral surface of the circuit 16. The spacing from the inner tips of the vanes 23 to the adjacent slow wave circuit portion 16 should be less than the spacing *g* between adjacent periodic elements of the circuit 16. The small axial gap *d* allows the interaction impedance of the slow wave circuit 16 to be maintained at a relatively high value. If the electrically conductive vane 23 occupies too much of the gap *g* between adjacent dielectric vanes 24, the conductive vanes 23 unduly increase the stored energy around the outside of the circuit 16, thereby reducing the interaction impedance. In a preferred embodiment, the thickness *w* of the metallic loading vanes 23 is approximately equal to one-half of the gap *g* between adjacent dielectric vane members 24.

The electrically conductive vanes 23 serve to prevent the wave energy traveling along meandering slow wave circuit 5 from fringing across the gaps between adjacent periodic elements of the slow wave circuit, i.e. across the gap *g*, especially at the low frequency end of the operating band where the wave length is relatively long compared to the spacing *g*. The improved dispersive characteristic for the vane loaded circuit 5 is shown by curve 21 of FIG. 3 for a condition wherein the inside diameter of the vane is equal to the inside diameter of the circuit 16. This should be contrasted with the dispersive characteristic of the circuit without loading vanes 23, as shown by curve 22. This improved dispersive characteristic greatly increases the operating

bandwidth of the tube and operating bandwidths in excess of 40 percent have been achieved while maintaining the relatively high power handling capability of the ceramic supported helix derived slow wave circuit **5.**

As shown by curve **21** of FIG. **3,** dispersion of the slow wave circuit **5** is almost completely eliminated if the inner diameter of the loading vane **23,** i.e. its degree of penetration into the slow wave circuit, is made the same as the inner diameter of the circuit **16.** However, this reduces the interaction impedance and so is not satisfactory to apply to the entire length of the slow wave circuit **16.**

The loading vanes **23** have very little effect on the phase velocity of the circuit **16** at the high frequency end of the operating band, whereas they have a relatively large effect at the low frequency end of the operating band. This is exactly the characteristic that is required to obtain optimum efficiency with circuit phase velocity tapering across the full frequency range. Therefore, to obtain optimum efficiency across the full octave frequency range, the phase velocity tapering of the microwave energy on the slow wave circuit is preferably achieved by varying the inner diameter of the metallic loading vanes **23** by decreasing the inner diameter thereof at the output end of the circuit, i.e. increasing the degree of penetration of the loading vanes **23.** As used herein the "output end of the circuit" is defined as shown in FIG. **1,** namely, the last three electronic wavelengths of the slow wave circuit **5,** i.e. three times the distance an electron of the beam travels in an RF cycle of the microwave signal frequency.

This increase in the penetration of the vanes **23** at the output of the circuit **5** has very little effect on the phase velocity at the high frequency end of the band where *b* is **2.** This can be seen by reference to FIGS. **3** and **8** where *b* is the velocity synchronization paremeter defined in the equation of FIG. **8.** Increasing the loading at the high frequency end of the operating band would actually degrade the performance of the tube. Thus, the vane loading, which has its greatest effect at the low frequency end of the band, provides a frequency dependent tapering of the phase velocity on the circuit to enhance efficiency at the low frequency end of the band where *b* is zero and where the loading has the greatest effect on efficiency. The improvement in efficiency for a vane loaded circuit, wherein the output end of the circuit is more heavily loaded by the vanes, i.e. their degree of penetration is greater, is as shown in curve **31** of FIG. **8,** wherein this efficiency is contrasted with the efficiency obtained with a uniform degree of penetration of the loading vanes throughout the length of the circuit as depicted by curve **32.**

The use of a voltage jump, i.e., an increase in the electron beam velocity at the output end of the traveling wave tube, has been shown to be even more effective than phase velocity tapering in enhancing efficiency of a traveling wave tube. The reason that the voltage jump is more effective is that it does not reduce the interaction impedance of the circuit as does phase velocity tapering.

Typical experimental results that have been achieved with voltage jumps are shown in FIG. **9.** As shown, RF conversion efficiency can be increased from 20 percent to almost 50 percent by the use of a voltage jump. A problem with utilizing a voltage jump is how to apply the voltage to the output section of a broad band helix derived circuit without breaking the circuit and interfering with its microwave properties.

However. the loading vanes **23** of the vane loaded helix derived circuit **5** provide a means for applying the voltage jump without breaking the RF circuit.

Referring now to FIG. **10** there is shown a cross-sectional view of the ceramic-comb-supported ring-and-bar helix-derived circuit **5** with the loading vanes **23** as shown in FIGS. **1–7.** In the embodiment as shown in FIG. **10,** throughout most of the length of the slow wave circuit, the vanes **23** are directly connected to the envelope **9** as illustrated in FIGS. **1–7.** However at the output end of the circuit **5,** where the voltage jump is to be applied, the loading vanes **23′** are connected at their roots to an electrically conductive plate **34** forming one plate of a capacitor which is spaced from the remaining portion of the envelope **9** via the intermediary of a ceramic sheet **35,** as of alumina or beryllia ceramic. This capacitor forms a microwave short between the loading vanes **23′** and the envelope **9,** but serves as a block to d.c. potential so that a high voltage can be applied to the vanes **23′** relative to the voltage applied to the circuit **16** and envelope **9.**

Thus, the capacitor formed by plate **34,** insulator **35** and the envelope **9** allows the voltage jump to be brought into the beam area without the requirement of isolating, for d.c. potential, two parts of the ring and bar helix derived circuit **16.** When the voltage jump is applied in this way, the voltage at the electron beam is periodic, i.e., the voltage as seen by the beam periodically increases in the regions between adjacent turns of periodic elements of the slow wave circuit **16.** The effective voltage jump is the average voltage along the circuit and this can be maximized to the required value shown in FIG. **9.** The effect of the periodic voltage increase is also beneficial to interaction efficiency.

Although the slow wave circuit **5,** as thus far described in the specification, has been a ring and bar circuit, the vane loading technique together with the increased penetration of the loading vanes at the output end of the tube and the provision of a voltage jump on the loading vanes is equally applicable to other types of helix derived slow wave circuits such as, meander line, double meander line, helix, cross wound helix, double ring and bar, and ladder line.

One electronic wavelength is the distance an electron of the beam travels in one cycle of the microwave signal wave energy. The increased penetration of the loading vanes and/or the voltage jump on the loading vanes to be effective in improving the efficiency of the traveling wave tube should be disposed in the final three electronic wavelengths of the output slow wave circuit portion, i.e. in the output end of the circuit **5.**

What is claimed is:

1. In a traveling wave tube:

means for forming and projecting a stream of electrons over a predetermined beam path;

periodic slow wave circuit means disposed along said beam path in electromagnetic wave energy exchanging relation with the stream of electrons for producing output electromagnetic wave energy;

a microwave ground plane structure disposed along said slow wave circuit and including periodic electrically conductive loading means projecting into the region between adjacent periodic elements of said periodic slow wave circuit means for decreasing the dispersiveness of said slow wave circuit

means, and wherein the degree of penetration of said periodic loading means into the region between adjacent periodic elements of said slow wave circuit varies along the length of said slow wave circuit to increase the radio frequency conversion efficiency of the traveling wave tube at the low frequency end of the operating band of the tube.

2. The apparatus of claim 1 wherein the degree of said penetration of said periodic loading means increases in the mean direction of microwave output power flow on said slow wave circuit.

3. The apparatus of claim 1 wherein said slow wave circuit means comprises a topologically equivalent helix circuit selected from the class consisting of, ring and bar, meander line, double meander line, helix, cross wound helix, double ring and bar, and ladder line circuits.

4. The apparatus of claim 3 wherein said microwave ground plane structure includes an electrically conductive barrel coaxially surrounding said slow wave circuit.

5. The apparatus of claim 4 wherein said periodic electrically conductive loading means comprises an array of electrically conductive vanes projecting from said ground plane structure into the region between adjacent electrically conductive elements of said slow wave circuit means.

6. The apparatus of claim 1 including, dielectric support means interposed between said microwave ground plane structure and said slow wave circuit for supporting said slow wave circuit relative to said ground plane structure, said dielectric support means including a plurality of dielectric vane portions spaced apart along the direction of the stream of electrons with the plane of each of said vanes being generally transversely disposed of the beam path, and wherein said periodic electrically conductive loading means includes an array of electrically conductive vane members with one of said loading members being interposed between adjacent ones of said dielectric vane portions, said loading vanes being electrically coupled for microwave energy to said microwave ground plane structure to provide a microwave ground disposed between periodic elements of said microwave circuit.

7. The apparatus of claim 6 wherein each of said electrically conductive loading vanes has a root portion adjacent said microwave ground plane structure and a tip portion adjacent said slow wave circuit, and wherein said tip portions of said loading vanes are closer to said slow wave circuit in a region of said vane loaded slow wave circuit that is displaced in the direction of microwave output power flow on said circuit from another region of said vane loaded slow wave circuit to increase the microwave conversion efficiency of the traveling wave tube.

8. The apparatus of claim 6 including, means for electrically isolating at least a portion of said electrically conductive loading vanes for d.c. operating potential relative to an upstream portion of said microwave ground plane structure to permit application of an independent operating potential to said electrically isolated portion of said loading vanes relative to the operating d.c. potential of said upstream portion of said ground plane structure for increasing the microwave conversion efficiency of the traveling wave tube.

9. In a traveling wave tube:

means for forming and projecting a stream of electrons over a predetermined beam path;

periodic slow wave circuit means disposed along said beam path in electromagnetic wave energy exchanging relation with the stream of electrons for producing output electromagnetic wave energy;

means for providing a microwave ground plane structure disposed along said slow wave circuit and including periodic electrically conductive loading means projecting into the region between adjacent periodic elements of said periodic slow wave circuit means for decreasing the dispersiveness of said slow wave circuit means, means for electrically isolating at least a portion of said periodic loading means for d.c. operating potential relative to an upstream portion of said ground plane structure to permit application of an independent operating potential to said electrically isolated portion of said loading means relative to the operating d.c. potential of said upstream portion of said ground plane structure for increasing the microwave conversion efficiency of the traveling wave tube.

10. The apparatus of claim 9 wherein each of said electrically conductive loading means has a root portion adjacent said microwave ground plane structure and a tip portion adjacent said slow wave circuit, and wherein said means for electrically isolating said upstream portion of said ground plane structure from said downstream portion of said loading means includes a capacitor means interposed between the root portions of said downstream electrically conductive loading means members and an adjacent portion of said ground plane structure.

11. The apparatus of claim 1 wherein the degree of penetration of said periodic microwave ground plane structure increases at the output end of said slow wave circuit.

12. The apparatus of claim 9 wherein said downstream electrically isolated portion of said loading means is disposed at the output end of said slow wave circuit means.

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