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**Scott**

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[54] **DUAL MODE TWT FOR LOW POWER CW AND HIGH POWER PULSED OPERATION**

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[52] **U.S. Cl.** .................... **315/3.6**, 315/3.5, 330/43
[51] **Int. Cl.** .................... **H01j 25/34**
[58] **Field of Search** .................... 315/3.5, 3.6, 39.73; 330/43

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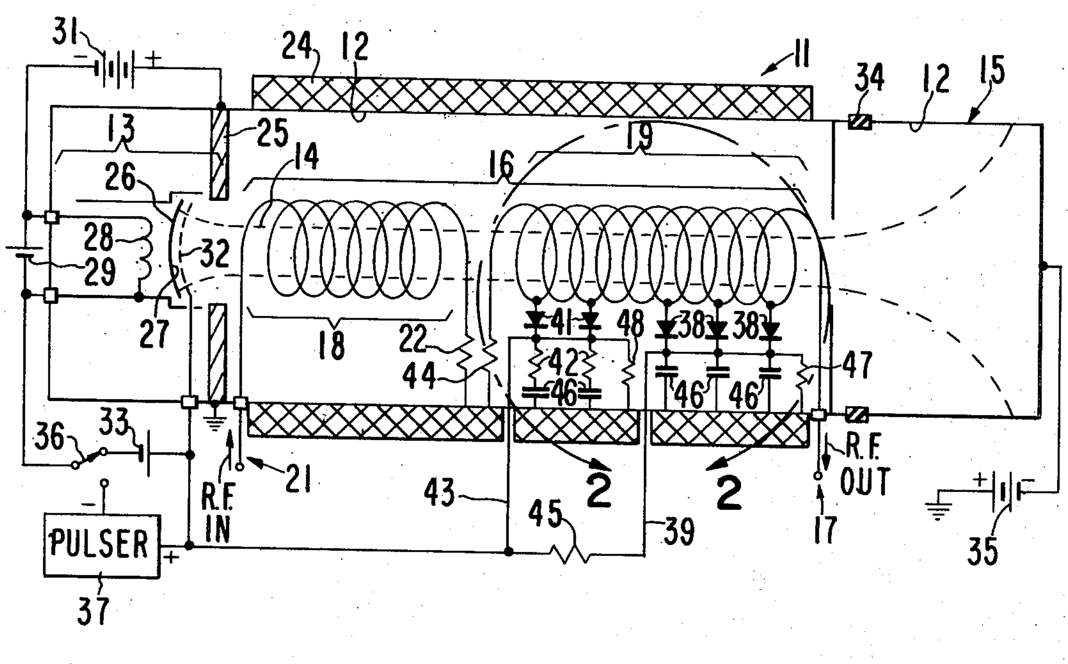
[57] **ABSTRACT**

A traveling wave tube is capable of operating over relatively wide bandwidths and with relatively high efficiency at one or the other of two different power output levels which are separated by as much as 10 db. The tube is switchable from one mode of operation to the other in a relatively short period of time, as of a few nanoseconds, by means of a control grid. In switching from the low power C.W. mode to the high power pulsed mode, the beam current is increased by a value of several times, as of five; the effective length of the output section of the slow wave circuit is automatically decreased; and the phase velocity on the output section of the slow wave circuit is decreased to maintain synchronism with the slow space charge wave of the beam.

**16 Claims, 6 Drawing Figures**



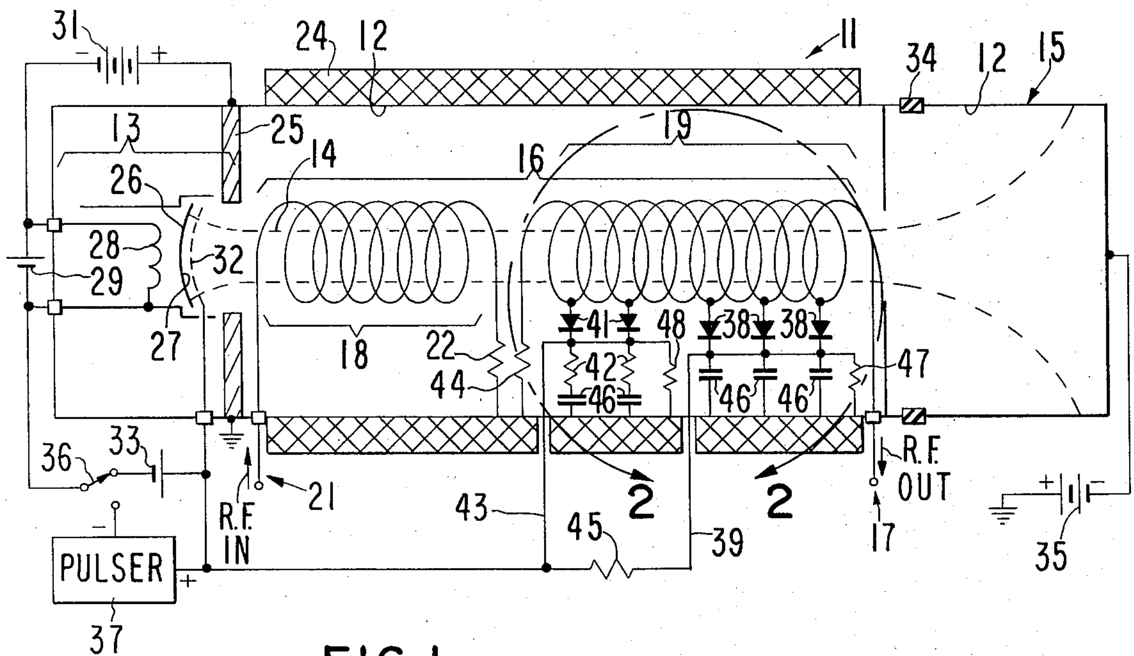



FIG. 1

FIG. 2

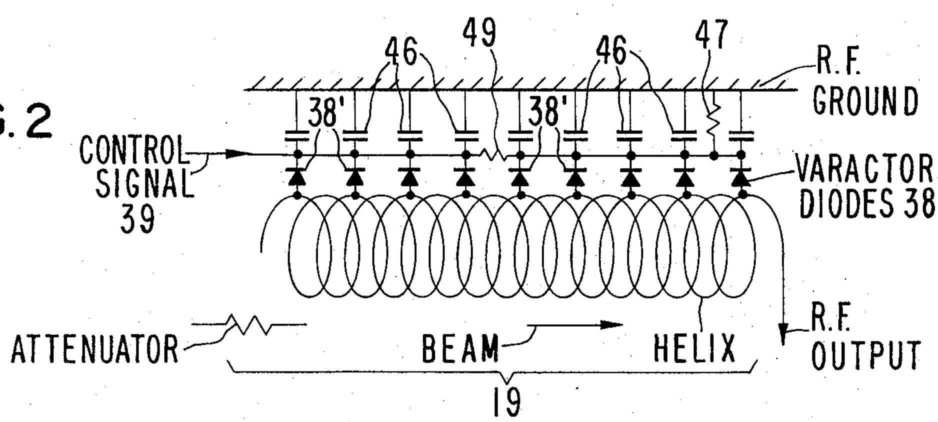



FIG. 3

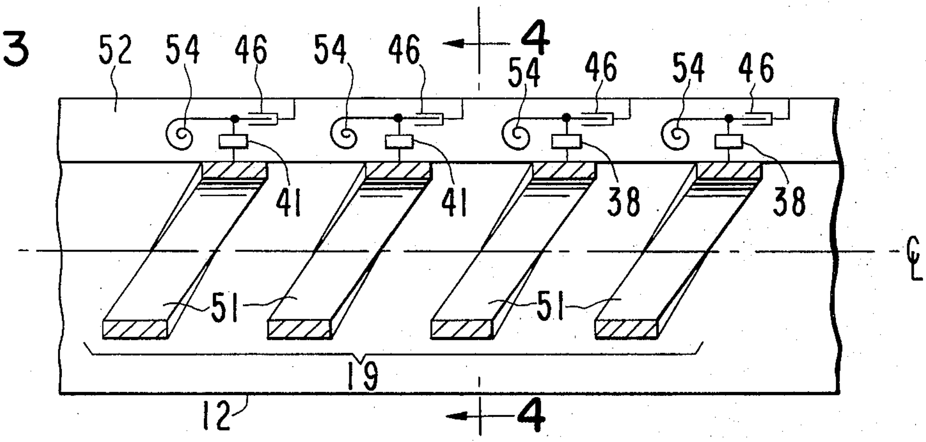


FIG.4

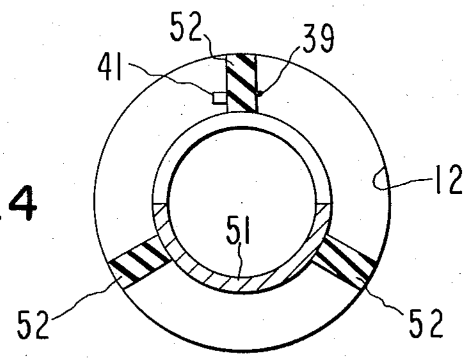



FIG.5

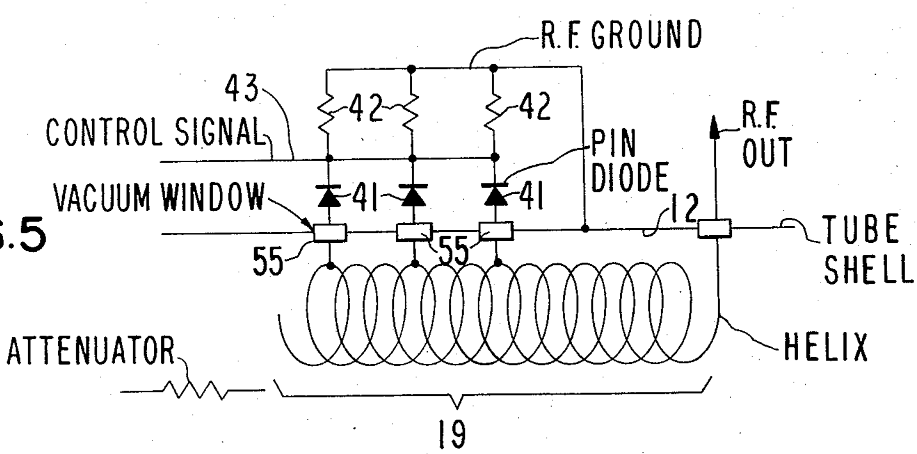
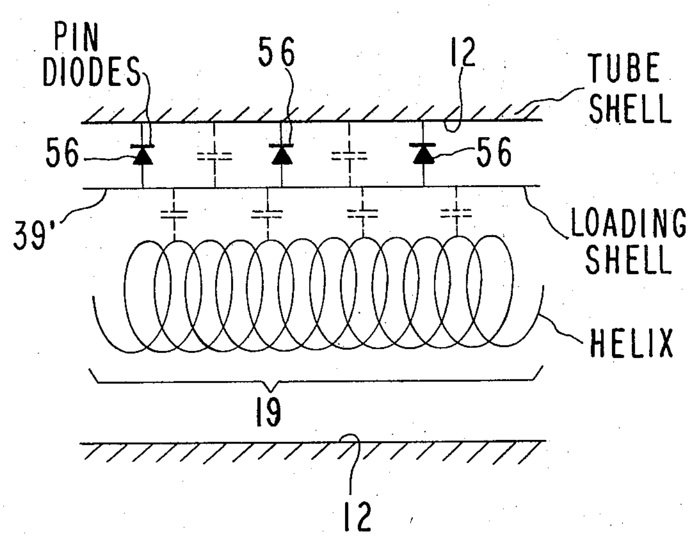



FIG.6



# DUAL MODE TWT FOR LOW POWER CW AND HIGH POWER PULSED OPERATION

## BACKGROUND OF THE INVENTION

The invention relates in general to traveling wave tubes and more particularly to an improved traveling wave tube capable of C.W. and pulsed mode operation at power levels differing for the two modes by as much as 10 db while maintaining relatively high RF conversion efficiency and bandwidth for both modes.

## DESCRIPTION OF THE PRIOR ART

Heretofore, there has existed, for many years, the requirement for a dual mode traveling wave tube that could operate over wide bandwidths and with high efficiency at one or the other of two different output power levels which were separated by as much as 10 db. The requirement for such a tube and a description of several attempts to achieve the aforecited specifications are described in an article titled "Will the Real Dual Mode T.W.T. Please Pulse On" appearing in *Microwaves*, October 1972, pages 58–63.

In a typical example, a traveling wave tube of this type should have a pulse power output of 10 kw peak power and provide an output of 1 kw of C.W. power. In either mode of operation the tube should have equally high efficiency, i.e. above 25 percent, and should maintain this high efficiency and dual mode power output capability over an octave or at least waveguide bandwidth, i.e. 40 percent. An alternative range of power levels might be 1 kw peak power and 100 watts of average power.

An additional requirement of the dual mode traveling wave tube, to make it practical for system use, is that it be switchable from one mode of power to the other in only a few nanoseconds. This nanosecond switching speed between modes necessitates that only a low voltage, low current switching element can be utilized to accomplish the power change.

The dual mode performance requirement is extremely difficult to achieve in a traveling wave tube for the following two reasons: First, for efficient beam-field interaction, the electron velocity must be synchronous with the microwave circuit wave phase velocity. This is difficult to obtain in two modes of operation where the beam power is 10 db different since the circuit wave should be in synchronism with the slow space charge wave even though the slow space charge wave velocity varies greatly with beam current. Secondly, the gain of the output section of the high power traveling wave tube is always chosen as a compromise between having enough gain for good efficiency and as little gain as possible to eliminate possibilities of oscillation. When the beam power changes by as much as 10 db from one mode of operation to the other, it is difficult to prevent oscillation in the high power mode while preserving good efficiency in the low power mode.

A simple approach for obtaining dual mode operation in a traveling wave tube is to keep the beam voltage constant and change the beam current over a 10 to 1 range by the use of a high mu grid. This approach is not successful because the space charge in the electron beam determines the synchronism that must be maintained between the electron beam velocity and the circuit wave velocity. Another way of stating this same fact is that the circuit velocity must be synchronous with the slow space charge wave velocity, and of course the slow space charge wave velocity is determined both by the initial electron velocity and by the amount of current in the electron beam.

The only possibility for maintaining synchronism in dual mode operations is to change both the current in the beam and the electron beam voltage at the same time. The change in electron beam voltage involves changing the high voltage on the electron beam, but this cannot be accomplished in the required nanosecond switching time.

Even if the requirement of nanosecond switching time were not necessary, the problem of the gain in the output section of the dual mode traveling wave tube still remains. In order to obtain good efficiency, the gain of the output section of the traveling wave tube must be at least 25 db. In most high power traveling wave tubes, the gain is maintained close to this minimum value to reduce the length of the output section as much as possible so that oscillations do not occur. If the output section length is selected to have 25 db gain in the low power CW mode of operation, then the increased gain that occurs with the 10 times higher beam current in the pulse mode will cause oscillation. Alternatively, if the output section length is chosen to have 25 db gain in the high current pulse mode so that oscillations do not occur, the output section will not have enough gain for even reasonable efficiency at the low current level of the CW mode.

The above two problems, that of maintaining synchronism between the slow space charge wave of the electron beam and circuit wave in two modes of operation, and that of obtaining enough length of the output circuit for good efficiency and not too much length for oscillation in the two modes of operation, are fundamental to traveling wave tube performance.

## SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved dual mode traveling wave tube for C.W. and pulsed mode operation.

In one feature of the present invention, means are provided, such as varactor diodes, PIN diodes, etc., connected in circuit with the output portion of the slow wave circuit for changing the phase velocity of the wave energy traveling on the slow wave circuit such as to maintain synchronism between the slow space charge wave of the beam and the circuit wave as the beam current is switched from one mode of operation to the other, whereby efficient dual mode operation is achieved.

In another feature of the present invention, means are provided, such as PIN diodes, varactor diodes, etc., coupled in circuit with the output portion of the slow wave circuit, such means being switchable in synchronism with changes in the beam current for changing the effective length of the output slow wave circuit portion such that the gain in the output circuit portion stays within reasonable limits so as to maintain efficiency and gain for both modes of operation.

In another feature of the present invention, varactor diodes are electrically coupled to the output section of the slow wave circuit. A bias potential is applied to such varactor diodes for changing the capacitive loading of the output section of slow wave circuit to maintain synchronism between the wave energy on the slow wave circuit and the slow space charge wave of the beam for substantially different conditions of beam power.

In another feature of the present invention, attenuator means are connectable to the upstream end of the output section of the slow wave circuit via the intermediary of PIN diodes, such diodes being switched into a conductive state concurrently with an increase in beam power to reduce the effective interaction length of the output section of the slow wave circuit to compensate for the increased gain of the output slow wave circuit with increased beam power.

In another feature of the present invention, diode means, responsive to a switching signal, are coupled to the output section of the slow wave circuit in such a manner as to shift the phase velocity of the circuit wave over a portion of the output circuit by an amount as to place that portion of the circuit out of synchronism with the slow space charge wave of the electron beam to compensate for increased gain of the output section with increased beam current.

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 block diagram form, of a traveling wave tube amplifier incorporating features of the present invention,

FIG. 2 is a schematic view of a portion of the structure of FIG. 1 delineated by line 2—2,

FIG. 3 is a physical realization of the circuit of FIG. 2,

FIG. 4 is a sectional view of the structure of FIG. 3 taken along line 4-4 in the direction of the arrows,

FIG. 5 is a schematic line diagram of an alternative embodiment of the present invention, and

FIG. 6 is a schematic line diagram of an alternative embodiment of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown a traveling wave tube 11 incorporating features of the present invention. The tube 11 includes an evacuated envelope 12 containing an electron gun assembly 13 at one end thereof for forming and projecting a beam of electrons 14 over an elongated beam path to a beam collector structure 15 disposed at the other end of the envelope 12.

A slow wave circuit 16 is disposed along the beam path 14 intermediate the electron gun 13 and collector 15 for cumulative electromagnetic wave interaction with the beam of electrons to produce an amplified output signal extracted from the slow wave circuit via output connector 17. The slow wave circuit 16 is divided into an upstream input section 18 and a downstream output section 19.

Wave energy to be amplified is fed onto the input slow wave circuit section 18 at the upstream end via an input connector or coupler 21. The phase velocity of the signal wave energy on the slow wave circuit 18 is chosen to be synchronous with the velocity of the slow space charge wave of the beam to produce amplification of the input microwave signal. The downstream end of the input slow wave circuit section 18 is terminated by an attenuator 22 which serves to absorb the amplified wave energy on the input section 18. However, the cumulative electromagnetic interaction between the circuit wave and the slow space charge wave produces a bunching of the electron beam in the input section 18 which is carried by the beam into the second or output section 19 of the slow wave circuit 16.

In the output section 19, the bunched electron beam excites a circuit wave on the output circuit 19 which cumulatively interacts with the beam to produce further velocity modulation and cumulative interaction to produce a greatly amplified output signal on the circuit. The amplified signal is extracted from the output section 19 via the output coupler 17 and fed to a suitable load, not shown.

The electron beam 14 is focused through the slow wave circuit 16 by a magnetic beam focus structure 24 coaxially disposed of the beam and the slow wave circuit 16 itself which focuses the beam in a non-intercepting manner. In a preferred embodiment, the beam focus structure 24 comprises a periodic permanent magnet focus structure of conventional design wherein the internal pole faces and spacers define the inside wall of the vacuum envelope 12. As an alternative, the beam focus structure 24 may comprise a solenoid producing an axial magnetic field.

The electron gun assembly 13 includes a centrally apertured anode 25 and a thermionic cathode 26 having a spherically concave cathode emitting surface 27 coaxially aligned with the central aperture in the anode 25. The electrostatic fields of the gun form and project a convergent flow of electrons through the central aperture in the anode 25. The cathode 26 is heated to thermionic emission temperature by a filamentary heater 28 energized with current from a supply 29 and disposed in heat exchanging relation with the cathode 26. An anode supply 31 supplies anode potential and beam current to the thermionic cathode emitter 26. A high mu non-intercepting control grid 32 overlays the spherically concave emitting surface 27 of the cathode 26 for controlling the beam current produced by the electron gun 13.

In the dual mode traveling wave tube 11, the control grid 32 is supplied with a predetermined fixed positive potential relative to that of the cathode 26 by supply 33 to enable a given power CW mode of operation at a given beam current. The collector electrode 15 is insulated from the envelope 12 via a cylindrical insulator 34 and is supplied with a negative potential by supply 35 to supply depressed collector operation to improve the overall efficiency of the tube.

A second, pulsed mode of operation is initiated by a switch 36 which switches the tube from the CW mode to a pulsed mode wherein a pulser 37 supplies pulses of positive potential to the control grid 32 for pulsing the beam current through the interaction circuit 16. The peak grid voltage supplied by pulser 37 to control grid 32 is sufficient to increase the peak beam current in the pulse mode, as contrasted with the CW mode beam current, by a factor of approximately five. A typical duty factor for the tube in the pulsed mode is approximately 5 percent.

With the increase in beam current for the pulsed mode of operation, the velocity of the slow space charge wave in the beam will be reduced as contrasted with the velocity of the slow space charge wave for the lower beam current in the CW mode. Therefore, in order to maintain synchronism between the slow space charge wave and the circuit wave in the output section **19** for the pulsed mode, a plurality of varactor diodes **38** are connected in shunt between the slow wave circuit **19** and the outer conductive shell or barrel of the tube. The varactor diodes are biased with a potential derived from the pulser **37** via lead **39** for capacitively loading the output portion of the slow wave circuit **19.** Diodes **38** reduce the phase velocity of the circuit wave for the signal wave energy to the velocity of the slow space charge beam wave to maintain synchronism and rf conversion efficiency for the tube **11.**

Also, since the gain of the output section **19** is dependent upon the value of beam current, the increased beam current for pulse mode operation greatly increases the gain of the output section **19.** A gain in excess of 25 db is undesired as excessive gain in the output section can produce undesired oscillation. Accordingly, a second set of diodes **41,** such as PIN diodes, are connected to the microwave ground or envelope **12** via attenuators **42** such that when the bias potential is applied from the output of the pulser **37** via lead **43,** the diodes **41** are biased into a conducting state for connecting the upstream portion of the output slow wave circuit section **19** to ground via the attenuators **42,** thereby effectively terminating or reducing the effective interaction length of the output slow wave circuit portion **19.**

Since the gain of the output section **19** is proportional to its length, pulsing the diodes **41** into a conductive state serves to effectively shorten the interaction length of the output section **19** to reduce the overall effective gain for the output section **19** to a suitable value, as of 25 db. The upstream end of the output section **19** is normally connected to attenuator **44** to inhibit undesired backward wave oscillations.

A resistor **45** in lead **39** serves to adjust the ratio of the bias voltages applied to the varactors **38** versus the bias potential applied to the PIN diodes **41.** DC blocking capacitors **46** are connected in series with each of the diodes **38** and **41** for blocking the DC bias potentials applied via lines **39** and **43** to the diodes **38** and **41,** respectively. Load resistors **47** and **48** are connected between each of the bias supply lines **39** and **43** and ground to develop the respective bias potentials thereacross.

Referring now to FIG. **2,** there is shown an alternative output slow wave circuit portion **19** incorporating an alternative embodiment of the present invention. The structure of FIG. 2 is similar to that of FIG. 1 with the exception that the PIN diodes which serve to shorten the overall length of the output slow wave circuit portion **19** are replaced by varactor diodes **38'.** The dc bias potential applied to the varactors **38** has two values produced by a voltage divider resistor **49** connected intermediate the length of dc bias supply lead **39** such that the bias potential applied across varactor diodes **38'** is substantially greater than the bias potential applied across varactor diodes **38.** In this manner, the phase velocity for wave energy on the slow wave circuit **19** is substantially different over the first part of the circuit controlled by varactors **38'** than over the second portion of the circuit controlled by varactors **38.** Thus, the pulsed control signal applied to lead **39** serves to shift the phase of the signal circuit wave over the upstream portion of the output circuit portion **19** sufficiently so as not to be synchronous with the slow space charge wave of the beam, thereby effectively shortening the overall interaction length of the output section of slow wave circuit **19.** The bias applied to the latter portion of the output circuit **19,** as loaded by bias varactor diodes **38,** serves to reduce the phase velocity of the signal wave energy on the circuit, as previously described with regard to the structure of FIG. **1,** to be synchronous with the slow space charge wave of the beam under the conditions of the increased beam current occasioned by the pulsed mode of operation.

Referring now to FIGS. **3** and **4,** there is shown a physical realization for a portion of the diode loaded output circuit portion **19** of FIG. **1.** In the structure of FIGS. 3 and 4, the output section of slow wave circuit **19** is formed by a tape helix **51** coaxially supported within the cylindrical bore of the envelope **12** by three ceramic rods **52** extending lengthwise of the helix **51.** The rods **52** are brazed at the inner and outer side edges to the helix **51** and barrel or bore of the tube **12,** respectively. One of the ceramic support rods **52** has formed thereon, as by printed circuit and integrated circuit techniques, the diodes **41** and **38,** respectively. The dc bias potential to be applied to the diodes is supplied via a printed circuit lead **39** printed onto the opposite side of the ceramic support rod **52** from the diodes. A dc connection is made through the rod **52** to the center of a spiral inductive RF choke **54.** Printed circuit blocking capacitors **46** serve as a microwave or radio frequency connection between the tubular envelope **12** and the helix **51** through the diodes **41** and **38,** respectively.

Referring now to FIG. **5,** there is shown an alternative embodiment of a portion of the structure of FIG. **1.** More particularly, FIG. **5** shows an arrangement of PIN diodes **41** connected for shorting (control signal applied on lead **43**) the upstream end of the output slow wave circuit portion **19** to ground through the attenuators **42.** The diodes **41** and attenuators **42** are disposed externally of the vacuum envelope **12;** the connection from the diodes **41** and attenuators **42** is made to the slow wave circuit **19** through wave permeable gas tight windows **55** formed in the envelope **12.** In this and other embodiments using attenuators **42,** the attenuators may be eliminated and the PIN diodes merely biased with a bias current intermediate those values of current representing full conduction and zero conduction of the diode. The internal resistance of the diode then forms the attenuator **42.**

Referring now to FIG. **6,** there is shown an alternative embodiment to the structure of FIG. **1** for changing the capacitive loading on the output section of slow wave circuit **19** for varying the phase velocity along the circuit **19.** More particularly, a metallic loading member **39'** which also serves as the lead for applying the phase control voltage to the output circuit is capacitively coupled to the slow wave circuit **19** and to the envelope **12.** A plurality of PIN diodes **56** are disposed in parallel with the capacitive coupling of the loading shell **39'** to the tube envelope **12.** The PIN diodes form a switchable connection for shorting out the capacitance between the tube shell **12** and the loading shell **39'.** When the capacitance between the loading shell **39'** and the tube shell **12** is shorted out via the bias potential applied to diodes **56** biasing the diodes conductive, the effective capacitive loading to the output portion of the slow wave circuit **19** is increased, thereby reducing the phase velocity of the signal wave energy on the output slow wave circuit portion **19**. The loading shell **39'** is dimensioned and spaced from the slow wave circuit **19** such that when the PIN diodes are biased into a conductive state, the loading to the slow wave circuit **19** is such as to reduce the phase velocity of the signal wave energy on the circuit **19** so that it is synchronous with the slow space charge wave of the beam, which has increased current occasioned by the pulsed mode of operation. A portion of the loading shell **39'** near the upstream end of the output circuit **19** can also be dimensioned such that when the diodes **56** are rendered conductive, the capacitive loading to that upstream portion of the output circuit **19** is increased sufficiently to cause the circuit wave on the output circuit **19** to have a velocity out of synchronism with the slow space charge wave of the beam, thereby effectively shortening the output slow wave circuit portion **19** to reduce the gain to prevent undesired oscillation.

Although, as thusfar described herein, the diode means for changing the phase velocity and the effective length of the output slow wave circuit portion **19** has been connected in shunt with the output circuit **19**, this is not a requirement. As an alternative, the diodes may be connected in series with the slow wave circuit as, for example, connected in between adjacent turns of the helix or between adjacent rings of a ring and bar circuit in parallel with the bars. Attenuators and blocking capacitors would be connected in series with the diodes for reducing the effective interaction length of the output circuit portion, whereas merely capacitors could be connected in series with the diodes for changing the effective velocity of the output circuit **19**. While a helix has been shown as the slow wave circuit in the structure of FIG. **3** this is not a requirement. Suitable alternative slow wave circuits would include, double meander line equivalents of the ring and bar circuit, and a vane loaded double meander line version of the ring and bar circuit as exemplified by U.S. Pat. No. 3,654,509, issued Apr. 4, 1972.

Also, as thus far described, the PIN and varactor diodes for changing the phase velocity and effective length of the output slow wave section **19** have been shown extending the full length of the output section **19**. This is not a requirement. In high power tubes, i.e., those with peak powers above 100 watts, the diodes, if employed all the way to the end of the output circuit, could have their peak inverse voltage ratings exceeded by the output signal wave energy on the circuit. Accordingly, the diodes for these high power tubes would not be used in the last few electronic wavelengths of output circuits where the RF field could exceed their ratings.

What is claimed is:

**1.** In a traveling wave tube:

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

slow wave circuit means diposed along the beam path so as to enable cumulative electromagnetic interaction between the stream of electrons and a flow of microwave signal power injected on said slow wave circuit means;

said slow wave circuit means including an output portion displaced in the direction of said microwave signal power flow from another portion of said slow wave circuit means;

means for changing the beam current from a first value to a second value at least a few times greater than that of the first value and for concurrently providing a switching signal; and

means coupled to said output portion of said slow wave circuit means and responsive to said switching signal for changing the phase velocity of the microwave signal power flow on said output portion of said slow wave circuit.

**2.** The apparatus of claim **1** wherein said means for changing the phase velocity of the microwave signal wave energy on said output circuit portion includes diode means connected in circuit with said output circuit portion, and means for applying said switching signal as a bias potential across said diode means.

**3.** The apparatus of claim **2** wherein said diode means comprises a voltage variable capacitance diode means such that by varying the dc bias potential applied from said switching signal across said diode means, the capacitance of said diode means as connected in circuit with said output portion of said slow wave circuit means is varied to change the phase velocity of the signal wave energy on said output portion of said slow wave circuit means.

**4.** The apparatus of claim **3** including evacuated envelope means containing therewithin said slow wave circuit means and said diode means.

**5.** The apparatus of claim **1** wherein said means for changing the phase velocity of the microwave signal energy flow on said output circuit portion includes capacitive loading means disposed in signal wave energy exchanging relation with said output portion of said slow wave circuit for capacitively loading said output portion of said slow wave circuit, and means responsive to said switching signal for varying the capacitive loading and thus the phase velocity of signal wave energy on said output circuit portion of said slow wave circuit.

**6.** The apparatus of claim **5** wherein said means responsive to said switching signal for varying the capacitive loading comprises, diode means connected in circuit with said capacitive loading means and said output portion of said slow wave circuit for varying the effective capacitive loading of said circuit in response to bias potential applied from said switching signal across said diode means.

**7.** The apparatus of claim **5** including an evacuated envelope containing said electron gun and slow wave circuit, said capacitive loading means comprising an electrically conductive structure capacitively coupled to said output portion of said slow wave circuit and also being capacitively coupled to said envelope, and wherein said means responsive to said switching signal includes diode means connected in shunt with the capacitance of said capacitive loading member and said capacitively coupled envelope for shunting out said last mentioned capacitance in response to said switching signal for varying the capactive loading on said output portion of said slow wave circuit means.

**8.** The apparatus of claim **2** including evacuated envelope means containing therewithin said electron gun means and said slow wave circuit means, electrically insulative support means interposed between said output portion of said slow wave circuit means and said envelope means for supporting said slow wave circuit within said envelope, and wherein said diode means is disposed on said insulative support means.

**9.** The apparatus of claim **1** including second means electrically coupled to said output portion of said slow wave circuit means and responsive to a switching signal for changing the effective cumulative beam-field interaction length of said output portion of said slow wave circuit.

10. The apparatus of claim 9 wherein said second means responsive to a switching signal comprises diode means connected in circuit with said output circuit portion of said slow wave circuit, and means for applying said switching signal as a bias potential across said diode means.

11. In a traveling wave tube:

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

slow wave circuit means disposed along the beam path so as to enable cumulative electromagnetic interaction between the stream of electrons and a flow of microwave signal power injected on said slow wave circuit means;

said slow wave circuit means including an output portion displaced in the direction of said microwave signal energy flow from another portion of said slow wave circuit means;

means for changing the beam current from a first value to a second value at least a few times greater than the first value and for concurrently providing a switching signal;

and means coupled to said output portion of said slow wave circuit means and responsive to said switching signal for changing the effective cumulative beam-field interaction length of said output portion of said slow wave circuit.

12. The apparatus of claim 11 wherein said means responsive to a switching signal comprises diode means connected in circuit with said output circuit portion of said slow wave circuit, and means for applying said switching signal as a bias potential across said diode means.

13. The apparatus of claim 12 wherein said diode means comprises varactor diode means responsive to the switching signal for changing the effective length of said output circuit by changing the phase velocity for signal wave energy on said circuit by a sufficient amount to cause the signal wave energy on a portion of said output portion of said slow wave circuit to be out of synchronism with the slow space charge wave of the electron beam.

14. The apparatus of claim 12 including attenuator means connected in circuit with said diode means and said output portion of said slow wave circuit such that said diode means is responsive to said switching signal to switch said attenuator means into wave energy exchanging relation with said output portion of said slow wave circuit for changing the effective length of and for terminating a portion of said slow wave circuit in a wave reflectionless manner.

15. The apparatus of claim 14 including evacuated envelope means containing therewithin said electron gun means and said slow wave circuit means, and said diode means and said attenuator means being disposed externally of said envelope means.

16. The apparatus of claim 12 wherein said diode means comprises PIN diode means.

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