United States Patent

Glance

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[45] **Nov. 7, 1972**

[54] **SHIELDED MEANDER LINE SLOW WAVE CIRCUIT AND TUBES USING SAME**

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[73] Assignee: **Varian Associates**

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

[56] **References Cited**

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Assistant Examiner—N. Moskowitz
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[57] **ABSTRACT**

A crossed field microwave amplifier tube is disclosed. The amplifier employs a meander line slow wave circuit arranged for interaction with a stream of electrons to amplify signal radio frequency wave energy on the circuit to produce an amplified output signal. The meander line slow wave circuit includes a zig-zag shaped conductor disposed over a ground plane member to define a meander line slow wave circuit. An insulative structure is disposed between the zig-zag conductor and the ground plane for insulatively supporting the zig-zag conductor over the ground plane. A conductive shield structure is provided which projects from the ground plane structure into the space between adjacent zig-zag portions of the zig-zag shaped conductor to decrease the capacitance between adjacent zig-zag portions of the meander line, thereby shaping the dispersion characteristic of the shielded meander line circuit to provide nearly constant phase velocity for r.f. wave energy within an ultra wide passband of the circuit. More particularly, the phase velocity within the passband of the circuit is constant to within 1 percent for 1 octave of bandwidth and constant to 1.5 percent for a 2 octave bandwidth. In a preferred embodiment, the insulative support structure is recessed into the ground plane structure to reduce the shunt capacity of the meander line to the dielectric support structure, thereby reducing the insertion loss of the circuit. In addition the conductive shield structure serves to shield the insulative support structure from sputtered cathode materials which would otherwise tend to be deposited on and to short out the insulative structure.

5 Claims, 7 Drawing Figures

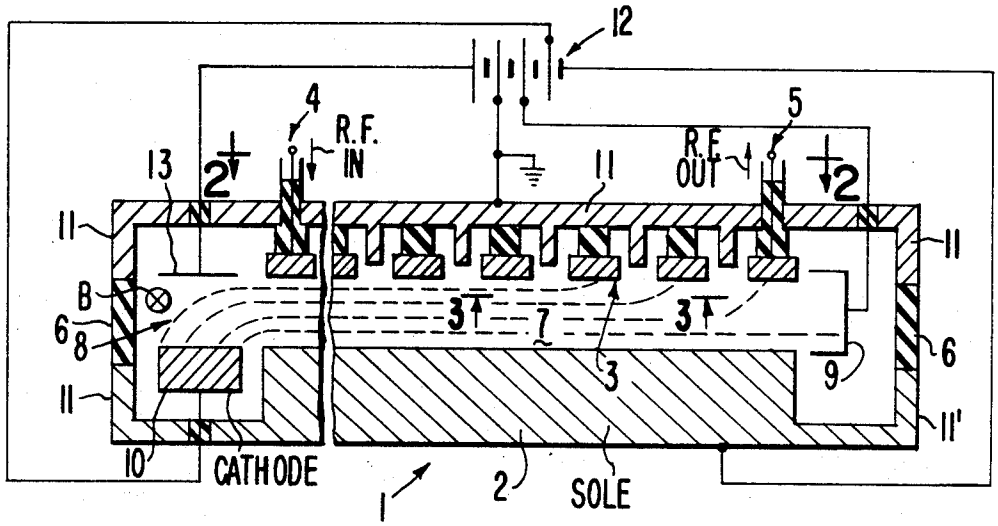


FIG. 1

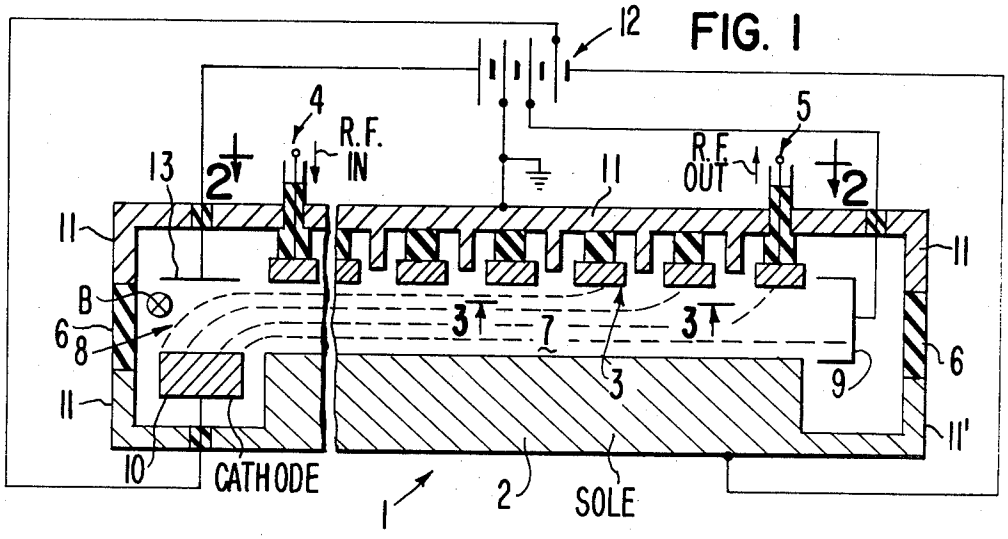


FIG. 2

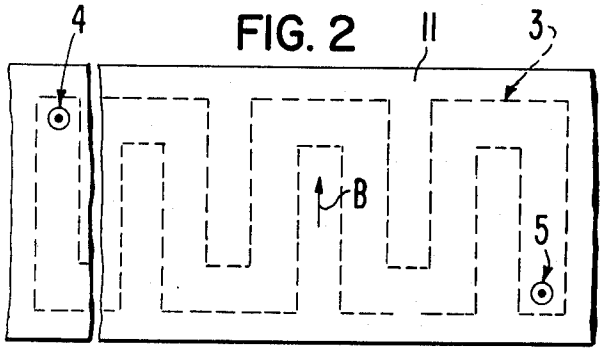


FIG. 3

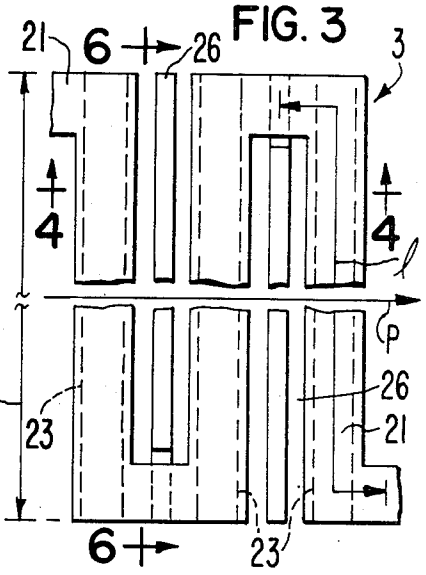


FIG. 4

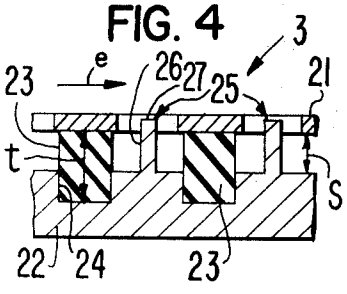
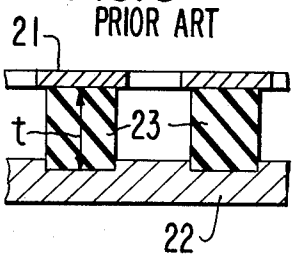


FIG. 5
PRIOR ART



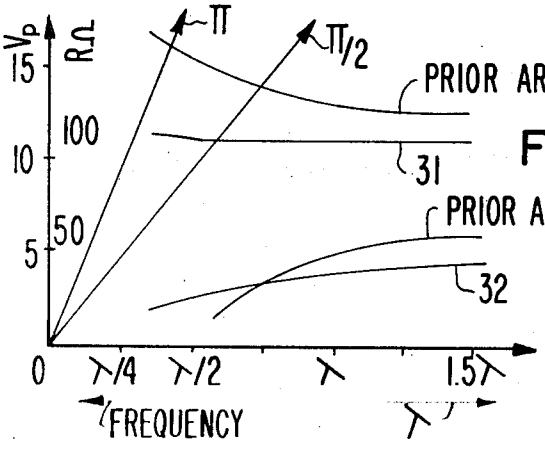
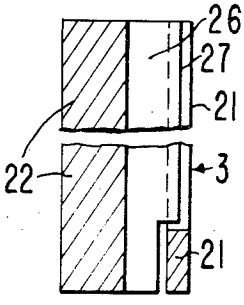


FIG. 7

FIG. 6



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SHIELDED MEANDER LINE SLOW WAVE CIRCUIT AND TUBES USING SAME

DESCRIPTION OF THE PRIOR ART

Heretofore, zig-zag shaped conductors have been supportively disposed over a ground plane member by means of a dielectric support structure to define a meander line circuit arranged for interaction with a stream of electrons in a crossed field geometry. In such a circuit the phase velocity for wave energy within the passband of the circuit varied approximately 15 percent over 2 octaves of bandwidth. Typically, only a 5 percent phase velocity variation can be tolerated over the frequency band of interest. Therefore, in the prior art meander line circuit, the bandwidth ratio for the tube was approximately 1.3 to 1 when operating in the vicinity of $\pi/2$ phase shift per period on the slow wave circuit. In addition, the dielectric support structure in the prior art meander line circuit served to provide substantial shunt capacity through the dielectric support to the ground plane which resulted in a substantial insertion loss for the circuit due to the r.f. loss associated with the brazed joints between the zig-zag conductor and the insulative support structure.

The meander line slow wave circuit is basically a desirable interaction circuit since it is relatively rugged and has relatively high thermal capacity, thereby permitting it to operate in microwave tubes operating in the power range of a few kilowatts average. However, a need exists for improvements in the circuit which will provide a more constant phase velocity over a wider band of frequencies. In addition, a need exists for modification of the circuit to reduce its insertion loss.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved meander line slow wave circuit and tubes utilizing same.

One feature of the present invention is the provision, in a meander line slow wave circuit, of a conductive shield structure projecting from the ground plane member into the region between adjacent zig-zag portions of the meander line for decreasing the capacity between adjacent zig-zag portions of the meander line, thereby providing a more constant phase velocity for wave energy on the circuit over a wider band of frequencies.

Another feature of the present invention is the same as the preceding feature wherein the insulative support structure for the zig-zag conductor of the meander line is recessed into the ground plane member to reduce the shunt capacity of the meander line circuit through the dielectric support structure, whereby the insertion loss for the shielded meander line circuit is substantially reduced.

Another feature of the present invention is the same as any one or more of the preceding features wherein the conductive shield structure is formed by a plurality of vane shaped members extending from the ground plane member into the region of space between adjacent zig-zag portions of the zig-zag conductor, such vane members being elongated in a direction transversely of the mean direction of power flow on the meander line slow wave circuit.

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 section foreshortened view of a cross field tube employing a shielded meander line circuit of the present invention,

FIG. 2 is a view of a portion of the structure of FIG. 1 taken along line 2—2 in the direction of the arrows,

FIG. 3 is an enlarged view of the portion of the structure of FIG. 2 taken along line 3—3 in the direction of the arrows,

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 sectional view similar to that of FIG. 4 depicting the prior art meander line circuit,

FIG. 6 is a sectional view of the structure of FIG. 3 taken along line 6—6 in the direction of the arrows, and

FIG. 7 is a plot of phase velocity V_p and interaction impedance R versus wavelength λ for the prior art meander line circuit and for the shielded meander line circuit of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1 and 2 there is shown a crossed field microwave amplifier tube 1 incorporating features of the present invention. The tube 1 includes an elongated non-emissive sole electrode 2 disposed opposite to and extending along an anode structure including a slow wave circuit 3 of the meander line type more fully disclosed with regard to FIGS. 3–6 below. The meander line 3 has an input terminal 4 at one end and an output terminal 5 at the other end. A crossed field elongated interaction region 7 is defined by the space between the sole 2 and the anode structure 3. A transversely directed magnetic field B is provided in the crossed field interaction region 7 by means of a magnetic structure, not shown.

A magnetron injection electron gun assembly 8 is provided at one axial end of the elongated interaction region 7 for injecting a beam of electrons axially into the elongated interaction region 7 and through the interaction region 7 to a beam collector structure 9 disposed at the other end of the sole 2. A vacuum envelope 11 as of copper encloses the aforedescribed elements and is evacuated to a low pressure as of 10^{-7} Torr. The envelope 11 includes an insulative ring 6 for insulating the upper half of the envelope 11 from its lower half 11'.

A power supply 12 supplies a negative potential relative to ground to the thermionic emitter or cathode 10 of the electron gun 8. The power supply 12 supplied a positive accelerating potential relative to the cathode potential, to the accelerating electrode 13 of the electron gun 8. The power supply 12 supplies a positive potential to the collector electrode 9 relative to the cathode potential. The power supply 12 supplies a negative potential to the sole electrode 2 relative to the cathode potential. The meander line slow wave circuit 3 forms an anode structure and is operated at ground potential.

In operation, the electron gun 8 injects a beam of electrons axially through the crossed-field interaction

region 7 to the beam collector 9. Radio frequency wave energy to be amplified is applied via terminal 4 to the meander line slow wave structure 3 for cumulative crossed-field type interaction with the electron beam to produce an amplified output signal which is extracted from the slow wave circuit 3 at output terminal 5 and fed to a suitable utilization device, not shown. The power flow of wave energy on the slow wave circuit 3 is directed parallel to the drift direction of the electrons as they pass through the crossed-field interaction region 7 to the collector electrode structure 9.

The intense r.f. electric fields of the meander line slow wave circuit interact with the beam in the elongated crossed-field interaction region 7 to form the beam into bunches of charge which are caused to cumulatively interact with the r.f. wave on the slow wave circuit 3. Crossed-field amplifier tubes of the general type shown in FIGS. 1 and 2 are conventional and may be of the linear format as shown or of a circular format, not shown.

Referring now to FIGS. 3, 4 and 6 there is shown in greater detail the shielded meander line slow wave circuit 3 of the present invention. The meander line circuit 3 includes a zig-zag shaped strip line conductor 21, as of copper, insulatively supported over a conductive ground plane member 22, as of copper, by means of an insulative support structure 23 formed by an array of rectangular cross section ceramic rods as of alumina or beryllia. The insulating support bars 23 are brazed to the zig-zag portions of the meandering strip line 21 along one side thereof and to the ground plane 22 along the other side and serve to provide a good thermal path for conduction of heat from the zig-zag conductor 21 to the ground plane member 22. In addition, the dielectric support bars 23 are preferably disposed within recessed portions 24 of the ground plane member 22 to decrease the shunt capacity of the dielectric support structure between zig-zag conductor 21 and the ground plane member 22. The dielectric support bars 23 are preferably recessed into the ground plane member 22 by at least an amount equal to 20% of the spacing S between the zig-zag conductor 21 and the ground plane 22.

A conductive shield structure 25 is formed by an array of conductive vane members 26, as of copper, which project from the ground plane member 22 into the space between adjacent zig-zag portions of the zig-zag shaped conductor 21 to decrease the capacitance between adjacent zig-zag portions of the zig-zag conductor 21. The dielectric support bars 23 and the conductive shielding vane members 26 are parallel to each other and are transversely disposed of the mean direction of power flow P on the meander line defined by the zig-zag conductor 21 disposed over the ground plane 22. The vane shaped shield members 26 have a free side edge portion 27 which terminates within the zig-zag conductor in the region of space defined between adjacent zig-zag portions of the zig-zag conductor 21.

Referring now to FIG. 5, there is shown the prior art meander line slow wave circuit 3' wherein the zig-zag conductor 21 is insulatively supported over the ground plane 22 by means of the insulative bars 23 without the provision of the substantial recess mounting of the dielectric bars 23 in the ground plane and without the provision of the conductive shield members 26.

The dispersion characteristic for a meander type slow wave circuit is expressed by the following formula:

$$\text{Cos } kd = \frac{\cos\theta}{1+2\frac{\gamma 1}{\gamma 0}\sin^2\theta} \qquad \text{Equation (1)}$$

where

$k=\omega/c$

ω = radian frequency,

c = velocity of light,

d = the length of the fingers (W in FIG. 3),

θ = phase shift per circuit section,

$\gamma 1$ = capacity per unit length between fingers, and

$\gamma 0$ = capacity per unit length to ground.

The shielded meander line circuit of the present invention as shown in FIGS. 3, 4 and 6, is a modification to the prior art meander line 3' of FIG. 5 to improve the dispersion characteristics of the circuit. In the present invention, the extension of the ground plane upwards between adjacent zig-zag portions of the zig-zag conductor 21 serves to decrease the capacity $\gamma 1$ per unit length between adjacent zig-zag portions of the zig-zag conductor 21 and to increase the capacity $\gamma 0$ per unit length to ground. At the same time, the thickness, t, of the ceramic insulator bars 23 is increased to offset the increase in $\gamma 0$ so that the capacity per unit length to ground $\gamma 0$ is kept about the same as in the prior art circuit. As shown by equation (1), the decrease in $\gamma 1$ while $\gamma 0$ is held constant results in a decrease in circuit dispersion. Maintenance of the same capacity to ground $\gamma 0$ maintains the same interaction impedance with the beam of electrons e. The increase in capacity $\gamma 0$ to the ground plane extension or shield 26 is thus offset by decrease in the capacity through the ceramic support bars 23 to ground.

The improved dispersion characteristics for the shielded meander line slow wave circuit of the present invention is shown in FIG. 7. More particularly, it is seen that the prior art meander line circuit has approximately a 15 percent change in phase velocity over a decade of bandwidth centered in the vicinity of $\pi/2$ phase shift per section. Typically, only a 5 percent velocity variation can be tolerated over the frequency band of interest. Thus, the prior art circuit of FIG. 5 has a relatively poor dispersion characteristic which precludes obtaining a decade of bandwidth. However, the shielded meander line circuit of the present invention has a dispersion characteristic as shown by line 31 and it is seen from this curve that the phase velocity is constant to approximately 1 percent over 1 octave of bandwidth and constant to approximately 1.5 percent over 2 octaves of bandwidth. This represents a substantial enhancement in the dispersion characteristic of the shielded meander line circuit of the present invention. The interaction impedance R of the circuit of the present invention is shown by curve 32 and compares favorably with the interaction impedance of the prior art circuit.

In addition, the shielded meander line slow wave circuit of the present invention has the additional advantage of concentrating the wave propagation between the shielding vane members 26 and the zig-zag portions of the zig-zag conductor 21 rather than concentrating the wave energy in the ceramic support structure between the zig-zag line 21 and ground plane

22 as found in the case of the prior art circuit of FIG. 5. This reduces the r.f. current flowing in the metal to ceramic seal regions between the zig-zag conductor 21 and the ground plane 22 and concentrates the currents instead in the metal surfaces on the edge of the zig-zag line and in the edge of the shield vane members 26. Since these surfaces are made of copper, which has a lower resistivity than does the metal-ceramic interface, the insertion loss is reduced by approximately 50 percent as compared to the prior art circuit.

In addition, removal of the r.f. field from the ceramic support structure decreases the dielectric loading of the ceramic support and thereby results in an increased meander line width *W* for a given phase shift or circuit section. This is advantageous because for a given output power the beam width is increased. This, in turn, reduces both cathode current density and the velocity variation of electrons in the beam. Reduced current density increases tube life and reduces velocity slip which improves the signal-to-noise ratio for the output signal. Furthermore, the shielding vane members 26 also serve as sputter shields for shielding the insulating members 23 from sputtered cathode material sputtered from the sole electrode 2 back toward the circuit 3. The vane members 26 intercept the sputtered material and prevent it from depositing over the insulators 23 to short out the meander line slow wave circuit. The π mode cutoff for the meander line circuit occurs when the length *W* (see FIG. 3) is equal to one-half an electrical wavelength long.

Although the shielded meander line circuit has been described employing a strip line conductor, i.e., having a width at least twice the thickness of the conductor, the zig-zag conductor need not be of the strip line type but may be of circular cross section such as, for example, a hollow tube through which a coolant may be passed for cooling the circuit. In addition, the shielded meander line of the present invention may be employed in circular geometry beam tubes both of the crossed-field and O-type.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention can be made without departing from the scope thereof it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a slow wave circuit, means forming a conductive ground plane structure, means forming a zig-zag-shaped conductor disposed over said ground plane to define a meander line slow wave circuit with said ground plane structure, the improvement comprising, means forming an insulative support structure disposed between said zig-zag conductor and said ground plane structure for supporting said zig-zag conductor over said ground plane structure, said insulative support structure being recessed into said ground plane structure by at least an amount equal to 20 percent of the spacing between said zig-zag conductor and said ground plane to substantially reduce the shunt capacity between said zig-zag conductor and said ground plane structure.

2. The apparatus of claim 1 further including a plurality of elongated conductive vane-shaped shield members projecting from said ground plane structure toward said zig-zag conductor, said vane-shaped conductors being elongated in the direction transversely of the mean direction of power flow on said meander line slow wave circuit.

3. The apparatus of claim 2 wherein said vane-shaped shield members have a free side edge portion which terminates within said zig-zag conductor in the region of space defined between adjacent zig-zag portions of said zig-zag conductor.

4. The apparatus of claim 3 wherein said zig-zag conductor is a strip line conductor having a thickness less than half its width.

5. The apparatus of claim 1 including means for projecting a stream of electrons adjacent a face of said zig-zag conductor on the side thereof faced away from said ground plane for electromagnetic interaction between the fields between adjacent zig-zag portions of said zig-zag conductor to produce amplification of wave energy on said meander line slow wave circuit, and means for extracting the amplified wave energy from said slow wave circuit.

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