Jan. 25, 1966 J. FEINSTEIN 3,231,780

MEANDERING SLOW WAVE CIRCUIT HAVING HIGH IMPEDANCE STUB SUPPORT MEANS

Filed Oct. 14, 1960

FIG. 1

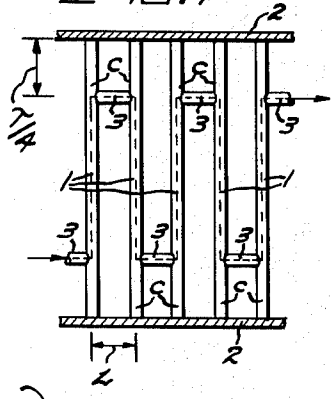


FIG. 2

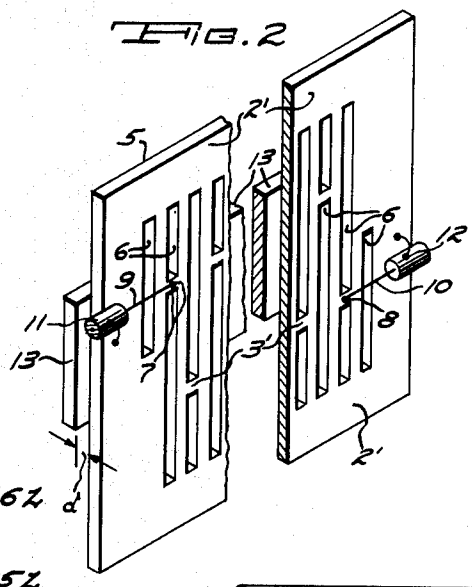


FIG. 3

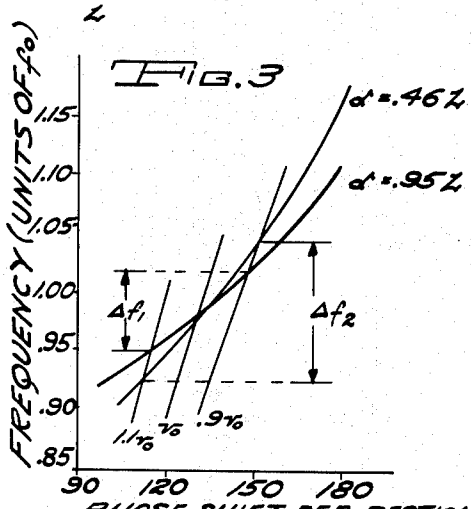


FIG. 5

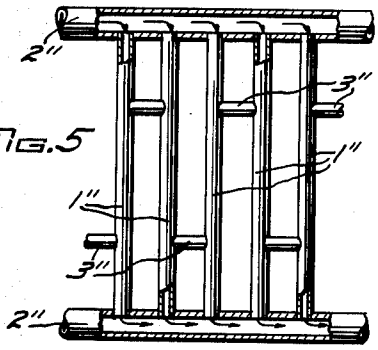


FIG. 4

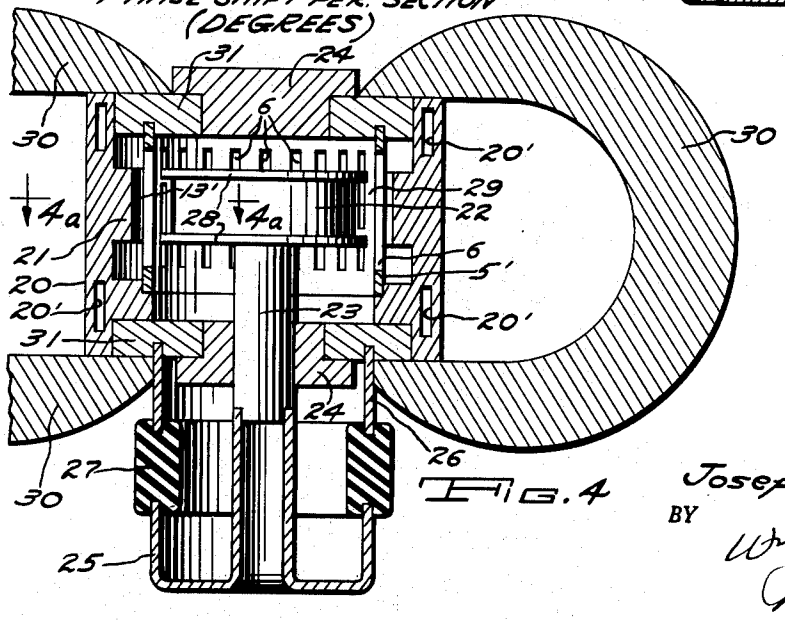
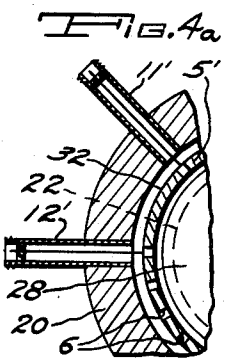


FIG. 4a



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United States Patent Office 3,231,780
Patented Jan. 25, 1966

3,231,780

MEANDERING SLOW WAVE CIRCUIT HAVING HIGH IMPEDANCE STUB SUPPORT MEANS

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Filed Oct. 14, 1960, Ser. No. 62,586
18 Claims. (Cl. 315—39.3)

This invention relates in general to microwave apparatus of the type wherein a traveling electromagnetic wave of retarded phase velocity interacts with a stream of charged particles, and more particularly to apparatus embodying a novel meandering line slow wave structure.

In many microwave applications it is desired to interact a constant velocity stream of electrons or other charged particles with traveling electromagnetic waves of widely varying frequencies. This requires that the phase velocities of the electromagnetic waves remain near the electron velocity, and hence substantially constant, over the frequency band of interest. One slow wave propagating structure which may be used for this purpose, known as a meandering line, consists of a conductor which winds back and forth in a direction perpendicular to the electron stream velocity so as to provide a substantial phase shift between adjacent sections of the winding distributed in the direction of the stream velocity, thereby propagating a wave of retarded phase velocity in this latter direction. The usefulness of such a delicate configuration, especially at high frequencies and high power levels, is, however, limited by complexity of construction and by inability to provide adequate heat dissipation.

Accordingly, it is the principal object of the present invention to provide microwave apparatus embodying a novel meandering line configuration characterized by a simple, rugged construction, and by enhanced power dissipation capabilities.

One feature of the present invention is the provision of a meandering line slow wave circuit structure for electron tubes and the like comprising a plurality of parallel conductors connected together by a plurality of alternately staggered, short, conductors spaced from the boundary members which join the extremities of said parallel conductors so that the portions of the parallel conductors extending between said staggered conductors to the adjacent boundary conductor form an effective high impedance choke to the flow of radio frequency currents to said boundary members, and yet provide a good thermal path for the efficient dissipation of the heat generated in the structure.

Another feature of the present invention is the provision of a meandering line slow wave structure in accordance with the preceding paragraph which is formed by means of a plurality of staggered slots in a metallic sheet.

Another feature of the present invention is the provision of a slow wave structure in accordance with the second preceding paragraph wherein said parallel conductors accommodate cooling fluid interior thereof.

A still further feature of the present invention is the provision of a novel crossed-field tube embodying a meandering line slow wave circuit.

These and other features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein,

FIG. 1 is an elevational view, partly in cross section, of a novel meandering line slow wave circuit structure in accordance with the present invention,

FIG. 2 is a fragmentary isometric view of a novel slotted plate embodiment of a meandering line slow wave circuit in accordance with the present invention,

FIG. 3 is a plot of the Brillouin dispersion curves for the structure of FIG. 2,

FIG. 4 is a novel cross-field amplifier tube embodying a meandering line slow wave circuit in accordance with the present invention,

FIG. 4*a* is a fragmentary cross-sectional view taken along direction 4*a* in FIG. 4, and

FIG. 5 is a novel fluid-cooled embodiment of a meandering line slow wave circuit in accordance with the present invention.

The basic meandering line configuration of the present invention shown in FIG. 1 comprises a plurality of vertical conductors **1** supported between an opposed pair of conducting boundary members **2**, and connected together by a plurality of alternately staggered, short, horizontal conductors **3** spaced a quarter wavelength away from the conducting members **2**. The radio frequency currents on this structure are confined to a meandering path, indicated by the dotted line, arranged so that the total length of path between adjacent sections places the phase shift per section within a range of broadband operation and the spacing L between adjacent sections yields the necessary phase shift per unit length for slowing the phase velocity of the horizontally progressing wave propagated by the structure to the approximate velocity of a horizontally directed electron stream passing adjacent thereto. The pair of vertical conductor portions *c* extending from each conductor **3** forms an effective high impedance double choke prohibiting the flow of radio frequency current to the supporting conductors **2**, and yet provides a good thermal path for the efficient dissipation of heat to the heat sink formed by the members **2**.

In FIG. 2 there is shown a slow wave structure in accordance with the present invention which is formed by a plurality of simple slots **4** in a metallic sheet or plate **5**, the metallic strip portions **1'**, **2'** and **3'** corresponding to the conductors **1**, **2** and **3**, respectively, in FIG. 1. Each end of the structure is terminated by a half wavelength slot **6** extending a quarter wavelength in each direction from the end terminals **7** and **8** so as to present a low impedance path to the inner conductors **9** and **10** of input coaxial connector **11** and output coaxial connector **12**, respectively. A ground plane plate **13** positioned parallel to circuit plate **5** may be included in order to permit the dispersion characteristics of the circuit to be varied as a function of the spacing *d* between the two plates. The vertical extent of plate **13** is preferably limited by the position of conductors **3'** in order to maintain a high impedance from conductors **3'** to conductors **2'**.

Referring now to FIG. 3, there are shown measured Brillouin (frequency vs. phase shift per section) dispersion curves of the waves propagated by the circuit of FIG. 2 for spacings *d* of .95 L and .46 L, where L is the distance between sections as indicated in FIG. 1. A useful measure of the amplification bandwidth Δf may be taken as that range of frequencies for which the phase velocity of the waves remain within 10 percent of the velocity v_0 of the interacting electron stream, the thin lines of FIG. 2 representing curves of constant phase velocity for these boundary values. For a midband phase shift of about 135°/section at the center frequency f_0, a bandwidth Δf_1 of 8 percent is obtained for d=.95 L (which corresponds closely to the bandwidth obtained by removing the ground plane to infinity), and a bandwidth Δf_2 of 15 percent is obtained for d=.46 L. Thus larger bandwidths, although at a decrease in interaction impedance, are obtained by the use of a closely spaced ground plane.

The application of the slow wave structure of FIG. 2 to a re-entrant type crossed-field amplifier is shown in FIG. 4. The cylindrical anode block **20** has an inwardly

extending projection 21 providing a ground plane 13' coaxially spaced from the cylindrical circuit sheet 5' which may be formed either by bending the flat plate of FIG. 2 or by cutting the slots through the surface of a metal tube.

A continuous cylindrical cathode 22, preferably a cold cathode made of a low work function material such as beryllium-copper, is supported coaxially within the tube by means of a stem 23 extending through the lower of a pair of header members 24 to mate with an annular cathode connector 25 which is separated from anode connector 26 by means of an insulating ring 27. The cathode 22 is bounded by a pair of end hats 28 which confine the emitted electrons to the interaction region 29 between the cathode 22 and the circuit plate 5'. A vertically directed magnetic field is provided in this interaction region by means of a permanent magnet 30 communicating with opposed annular pole pieces 31 which are secured in a vacumm sealing manner, as by brazing, between anode block 20 and headers 24. The crossed electric field in the region 29 is provided by means of a negative voltage applied between anode connector 26 and cathode connector 25.

In operation, a signal which it is desired to amplify is fed to the circuit plate 5' via input coaxial connector 11' and establishes a traveling wave in the interaction region 29. The injection of this wave will be sufficient to initiate the emission of electrons in the case of a cold cathode 22, and this emission will remain continuous without the necessity of supplying external heating power by secondary emission due to back bombarding electrons which have gained energy from the wave. The interacting electron stream moves through the region 29 with a clockwise circumferential velocity determined by the ratio of electric to magnetic field. The phase velocity of the traveling wave is approximately synchronous with the stream velocity for a wide band of frequencies so that the electrons deliver energy to and amplify waves within this band, the amplified output signal being led out via output coaxial connector 12'. The slow wave circuit is interrupted between the input and output connectors 11' and 12' to provide a drift segment 32 of sufficient length to permit electron debunching so that the electrons may reenter the interaction region for improved efficiency without producing undesired internal feedback. The heat generated in the circuit structure 5 flows through conductor portions 2' and is dissipated in the anode block 20 which is fluid cooled through channel 20'.

It should be noted that whereas the slow wave structures in accordance with the present invention are useful with various types of traveling wave tubes, they are particularly useful in crossed-field or M-type tubes where an extensive interaction region is required, and also where the larger interception of electron current and the close spacing of sections required for operation at the lower electron velocities of these tubes intensify the problems of construction and heat dissipation. Such cross-field tubes include versions wherein the interaction region is colinear and also injected beam versions (both colinear and re-entrant) in which the emitting cathode is outside of the interaction region. The combination in a crossed-field tube of a meandering line with a continuous cathode—that is, one emitting electrons throughout the entire interaction region—as shown in FIG. 4 is of special importance in view of the tendency of the backward wave fundamental of space harmonic structures, for example, interdigital lines, to interfere with the electron bunching process required for proper operation with this type of cathode.

FIG. 5 shows a further embodiment of a slow wave structure in accordance with the present invention wherein the vertically extending conductors 1'' comprise a plurality of hollow tubes extending between supporting tubular boundary members 2''. Enhanced heat dissipation is then conveniently obtained by circulating cooling fluid, such as water, as indicated by the arrows, utilizing the hollow upper and lower tubes 2'' as an input and output manifold, respectively.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could 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. A slow wave structure comprising, a pair of opposed boundary members extending in the direction of circuit development, a plurality of periodically spaced, substantially linear, parallel conductors conductively and transversely interconnecting said boundary members and being joined at their extremities to said boundary members, a first plurality of alternating conductors spaced from one of said boundary members and connecting each of said parallel conductors to the parallel conductor on one side thereof and defining one side boundary of a meandering slow wave circuit formed by said first mentioned parallel conductors, and a second plurality of alternating conductors spaced from the opposite boundary member in staggered relation with respect to said first plurality of alternating conductors and connecting each of said parallel conductors to the parallel conductor on the other side thereof and defining a second side boundary of said meandering slow wave circuit opposite to said first side boundary, the portions of said parallel conductors extending from each alternating conductor to said closest boundary member providing a circuit path to said boundary member for wave energy propagating on said meandering slow wave circuit which has a high impedance compared to the impedance of the circuit path between adjacent parallel conductor members over said alternating conductors.

2. A slow wave structure according to claim 1 wherein the distance between each of said alternating conductors and the boundary member closest spaced therefrom is one quarter wavelength.

3. The slow wave structure of claim 1 further including ground plane means closely adjacent said parallel conductors and limited in extent to the region between said first and second plurality of alternating conductors.

4. The slow wave structure of claim 1 wherein said parallel conductors, said boundary members, and said alternating conductors are defined by a conducting sheet having staggered, parallel slots therein.

5. The slow wave structure of claim 4 wherein said sheet has an end slot adjacent an alternating conductor at each end of said plurality of parallel conductors, said end slots extending a quarter wavelength in each direction from said end conductors whereby said end conductors provide low impedance input and output terminals for the propagation of wave energy along said structure.

6. The slow wave structure of claim 1 wherein said parallel conductors are hollow tubes adapted to pass cooling fluid therethrough.

7. The slow wave structure of claim 6 wherein said boundary members are hollow so as to provide an input manifold and an output manifold for the fluid passing through said hollow tubes.

8. In an electron tube, the combination comprising: a slow wave structure having, a pair of opposed boundary members extending in the direction of circuit development, a plurality of periodically spaced, substantially linear, parallel conductors conductively and transversely interconnected said boundary members and being joined at their extremities to said boundary members, a first plurality of alternating conductors spaced from one of said boundary members and connecting each of said parallel conductors to the parallel conductor on one side thereof, and a second plurality of alternating conductors spaced from the opposite boundary member in staggered

relation with respect to said first plurality of alternating conductors and connecting each of said parallel conductors to the parallel conductor on the other side thereof, said first parallel conductors and said first and second pluralities of alternating conductors defining a meandering slow wave circuit, the portions of said parallel conductors extending from each alternating conductor to said closest boundary member spaced therefrom providing a circuit path to said boundary member which has high impedance compared to the impedance of the circuit path between adjacent parallel conductor members over said alternating conductors so that radio frequency energy is confined in a meandering path defined by said first parallel conductors and said first and second pluralities of alternating conductors for establishing a traveling wave of retarded phase velocity adjacent said structure; and means for setting up a stream of electrons adjacent to said structure which delivers energy to said traveling wave and amplifies the same.

9. The combination of claim **8** further including means for providing crossed electric and magnetic fields is the wave-electron interaction region adjacent said slow wave structure.

10. In an electron tube, the combination comprising: first extended electrode means, second extended electrode means spaced from said first electrode means and forming an interaction region therebetween, at least one of said electrode means having a slow wave structure as defined in claim **1** associated therewith for propagating radio frequency energy in a meandering path whereby a traveling wave of retarded phase velocity is established in said interaction region and progresses in the extended direction of said electrodes, means for establishing a negative voltage between said second electrode means and said first electrode means, and means for establishing a magnetic field in the space between said first and second electrode means in crossed relation with respect to the electric field established by said voltage so that electrons moving in said interaction space deliver energy to said traveling wave and amplify the same.

11. The combination of claim **10** wherein said electrons are emitted by said first electrode means.

12. The combination of claim **10** wherein said electrons are emitted by a cathode external to said second electrode means.

13. An electron tube comprising an electron emissive cylindrical cathode, slow wave circuit means having a structure as defined in claim **1** coaxially spaced from said cathode to form a re-entrant interaction region therebetween for confining electromagnetic energy to a meandering path whereby a traveling wave of retarded phase velocity progresses circumferentially about said interaction region, means for feeding electromagnetic energy to said circuit means to thereby establish said traveling wave, means for establishing a negative voltage between said circuit means and said cathode, means for establishing a magnetic field in said interaction region in crossed relation with respect to the electric field established by said voltage so that electrons emitted by said cathode are circumferentially deflected and deliver energy to said traveling wave, and means for extracting amplified electromagnetic energy from said circuit.

14. An electron tube according to claim **13** wherein said energy feeding means and said energy extracting means are separated by a drift space of sufficient length to effect electron debunching before the electrons reenter said interaction region.

15. An electron tube according to claim **13** wherein said circuit means is supported coaxially within an anode housing, said anode housing having an inwardly projecting portion providing a ground plane as defined in claim **3** outwardly spaced from said circuit means.

16. An electron tube according to claim **15** wherein said slow wave circuit comprises a cylindrical conducting sheet having staggered slots therein.

17. An electron tube apparatus including, means for producing a stream of electrons, a slow wave structure disposed adjacent said electron stream for electromagnetic interaction therewith, said slow wave structure comprising, a pair of opposed boundary members extending in the direction of circuit development, a plurality of regularly spaced parallel conductors conductively and transversely interconnecting said boundary members and being joined at their extremities to said boundary members, a first plurality of transverse conductors spaced from one of said boundary members and closer to this boundary member than to the opposite boundary member and connecting alternate parallel conductors to the parallel conductor on one side thereof, a second plurality of transverse conductors spaced from the opposite boundary member and closer to this boundary member than to the first-named boundary member and connecting the said alternate parallel conductors to the parallel conductor on the other side thereof forming a meandering slow wave circuit, the outer portions of the parallel conductors extending from each transverse conductor to the boundary member closer thereto providing a circuit path to said boundary member for wave energy propagation on said meandering slow wave circuit which has a high impedance compared to the impedance of the circuit path between adjacent parallel conductor members over said alternating conductors, and a ground plane member disposed adjacent the active portions of said parallel conductors which extend between said transverse conductors and spaced from said active portions by a distance such that the bandwidth of the structure is substantially increased.

18. The apparatus according to claim **17** wherein the distance between the ground plane and said active portions is substantially less than the spacing between adjacent ones of said parallel conductors.

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