July 28, 1964 J. W. SULLIVAN 3,142,777

TRAVELING WAVE TUBES HAVING HELIX DERIVED SLOW-WAVE CIRCUITS WITH TAPERED SUPPORT STUBS AND LOADING MEANS

Filed July 15, 1963

FIG.1

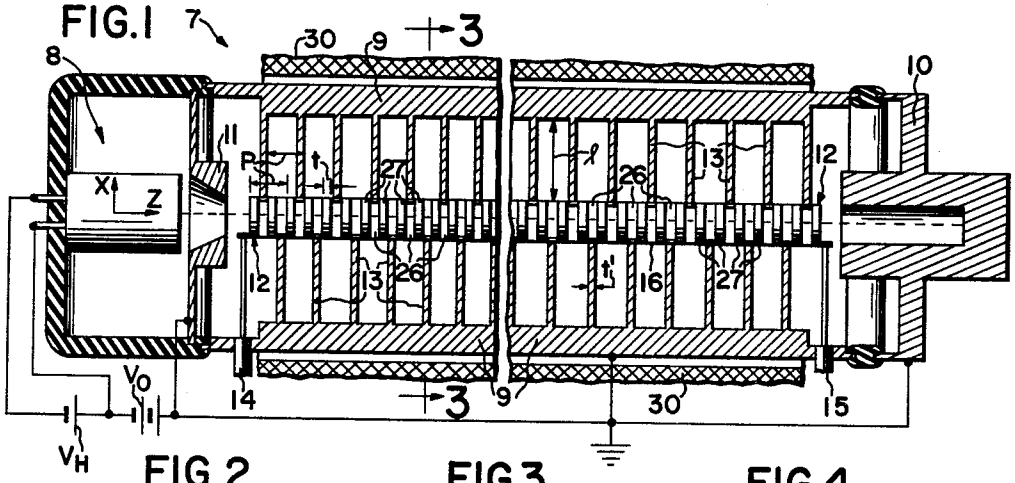
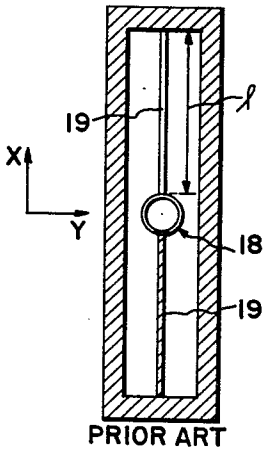


FIG.2



PRIOR ART

FIG.3

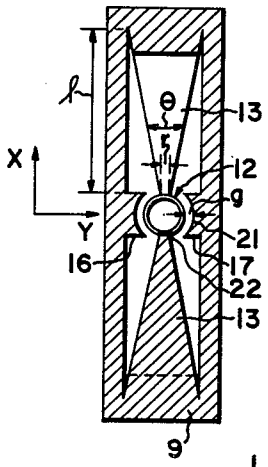


FIG.4

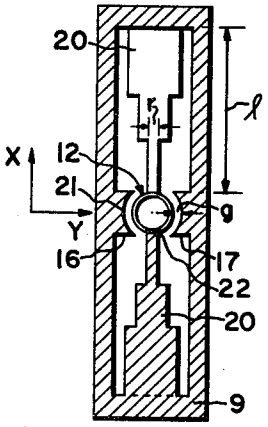


FIG.5

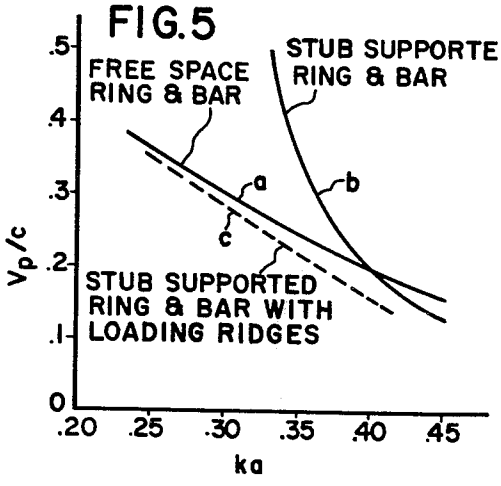
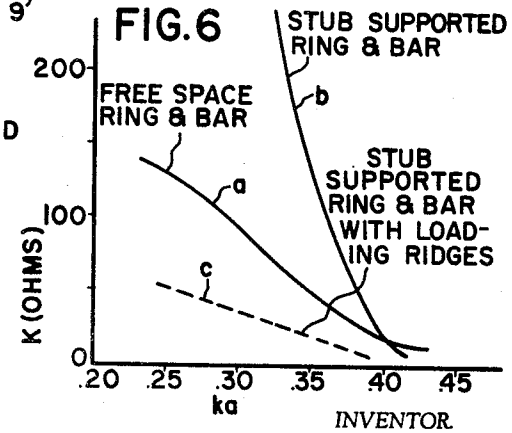


FIG.6



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TRAVELING WAVE TUBES HAVING HELIX DERIVED SLOW-WAVE CIRCUITS WITH TAPERED SUPPORT STUBS AND LOADING MEANS

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16 Claims. (Cl. 315—3.5)

This invention is concerned in general with high frequency electron discharge devices and more specifically with traveling wave tubes and slow wave circuits therefor.

Traveling wave tubes are finding increased usage in many diverse applications such as, for example, wide band communication systems for C.W. operated traveling wave tubes and as drivers for high power klystrons or other high power tubes such as crossed-field devices for pulse operated traveling wave tubes. Of primary concern in such traveling wave tubes is the slow-wave circuit employed therein and especially the dispersion, interaction impedance and thermal properties thereof.

The present state of the art helix and helix-derived slow wave structures employed in traveling wave tubes have good bandwidth and impedance characteristics at lower power levels of operation such as, for example, 500 watts C.W. at S band. However, when attempts are made to operate such structures at higher power levels, such as, for example, above 1 kw. C.W. at S band, thermal problems become increasingly pronounced. Suitable means for dissipating the increased heat generated on the slow wave structure by the increased R.F. powers flowing along the circuit are a critical requirement for satisfactory operation of traveling wave tubes at such higher power levels.

Attempts have been made to solve the thermal problem by increasing the cross-sectional area of the helix or the cross-sectional area of the rings and connecting bars in a helix-derived ring and bar slow wave structure. Such techniques have proved to be unsatisfactory solutions since, while the thermal conductivity of the circuit was enhanced, the interaction impedance was degraded approximately proportional to the increased thermal advantages derived from the increased circuit cross-sectional area. Therefore, other solutions to the thermal problem must be found which do not degrade the interaction impedance or gain-per-unit-length if satisfactory C.W. operation at higher power levels of such helix-derived circuits as the ring and bar slow-wave circuit is to be achieved.

Supporting stubs for ring and bar slow-wave structures have been proposed as a means of enhancing the thermal properties for high power levels of operation. Both radial and tangential supporting stubs of constant cross-sectional area have been employed to enhance the thermal properties of contra-wound helices and ring and bar circuits. Such schemes have proved to enhance the thermal properties of the circuit as would be expected but the deleterious effect on bandwidth of such supporting techniques due to increased dispersion has heretofore seriously limited the usefulness of such stub supporting techniques. An example of such prior art stub supporting techniques can be found in U.S. Patent No. 2,853,642 by C. K. Birdsall et al.

The present invention provides a novel supporting structure for such helix derived circuits as the contra-wound helix and ring and bar slow wave circuits which overcomes the aforementioned problems and permits traveling wave tube operation at increased power levels without seriously degrading interaction impedance and bandwidth. This is accomplished through the utilization of a novel stub-supported, ridge loaded slow-wave circuit wherein the incorporation of tapered stub supports and

loading ridges in such helix-derived circuits as the ring and bar and contra-wound helix provide excellent thermal dissipation characteristics coupled with excellent dispersion and interaction impedance characteristics at high power levels of operation. The above mentioned operating characteristics are achieved in the present invention by the expedient of minimizing energy storage between adjacent stubs while maximizing the thermal properties of the stubs and by additionally providing specific loading ridges to optimumly compensate for the increased dispersion caused by the addition of the support stubs.

A principal object of the present invention is, therefore, the provision of a novel slow-wave circuit having improved thermal properties for high power operation.

A feature of the present invention is the provision of a helix-derived slow-wave circuit having novel supporting and loading means therefor.

Another feature of the present invention is the provision of a ring and bar slow-wave circuit having tapered supporting stubs and ridge loading means wherein improved thermal dissipation, dispersive and interaction impedance characteristics for the particular slow-wave structure are achieved in comparison with a ring and bar slow-wave circuit having non-tapered supporting stubs.

Another feature of the present invention is the provision of a stub supported, ridge loaded ring and bar slow-wave circuit of the type characterized in the preceding feature wherein the tapered stub is approximately by periodically stepping the supporting stub.

Another feature of the present invention is the provision of a contra-wound helix slow wave structure supported and loaded in the manner set forth in the two preceding features.

Still another feature of the present invention is the provision of an electron discharge device such as a traveling wave tube which incorporates the novel slow wave circuits of the aforementioned features.

These and other features and advantages of the present invention will be more apparent after a perusal of the following specification taken in conjunction with the accompanying drawings, wherein

FIG. 1 is a longitudinal cross-section view, partly in elevation, of a traveling wave tube incorporating the novel slow wave structure of the present invention,

FIG. 2 is a typical prior art stub supported ring and bar slow wave circuit,

FIG. 3 is a cross-sectional view taken along the section line 3—3 of FIG. 1 depicting the novel slow wave circuit of the present invention,

FIG. 4 is a cross-sectional view of another novel slow-wave circuit wherein the taper supporting stubs are approximated by means of a series of stepped portions,

FIG. 5 is a dispersion diagram of various slow-wave circuits wherein a comparison of the dispersion characteristics of the circuits is depicted, and

FIG. 6 is a diagram depicting interaction impedance v. normalized frequency referred to the average ring radius of the slow-wave circuit for various ring and bar slow-wave circuits.

Referring now to FIG. 1 of the drawings, there is shown a traveling wave tube **7** having an electron gun structure **8**, conductive body **9**, collector **10**, anode **11**, helix-derived ring and bar type slow wave circuit **12** defining a series of interaction gaps **26** between spaced rings **27**, supporting stubs **13**, R.F. input and output coupling means **14** and **15**, respectively, focusing solenoid **30**, and heater and beam voltage supplies, V_H and V_O respectively. The longitudinal extent of the conductive body or waveguide **9**, defines a predetermined line of circuit development about which the helix derived ring and bar type slow-wave circuit **12** is disposed. The guide **9** and accompanying slow-wave circuit with loading ridges **16**,

17 and supporting stubs 13 are probably best defined by reference to a conventional X–Y–Z co-ordinate system as shown. The conductive body 9 serves the multiple functions of providing a conductor for the application of a D.C. beam voltage for the slow-wave circuit, acting as a heat sink for improving the thermal characteristics of the slow wave circuit and acting as an extremely rugged support structure. The slow-wave circuit of FIG. 1 is additionally provided with loading ridges 16, 17 as shown in the cross-sectional view of FIG. 3. The circuits of FIGS. 1–4 are defined directionally with reference to the X–Y–Z rectangular co-ordinate system as shown.

It is not thought necessary to present any detailed discussion of traveling wave tube operation since the literature on this subject is replete. It should suffice to point out that the traveling wave tube of the present invention can be operated C.W. as shown or can be provided with suitable pulse modulating means for pulsed operation in a manner well known in the art.

It is further contemplated that the novel slow-wave structure of the present invention could also be operated as a backward wave oscillator with suitable modifications well known to those skilled in the art.

The stubs 13, slow-wave circuit 12, collector 10, conductive shell 9 and loading ridges 16, 17 are all preferably made of a material such as O.F.H.C. copper.

Directing our attention to FIG. 2, there is shown a typical prior art stub supported ring and bar slow-wave circuit 18. The ring and bar and contra-wound helix types of helix-derived slow-wave circuits are shown and described in U.S. Patent 2,937,311 by M. Chodorow and in U.S. Patent 2,836,758 also by M. Chodorow. The stubs 19 are linear and non-tapered. In comparison therewith FIG. 3 shows the novel tapered stubs 13 supporting ring and bar circuit 12 coupled with the loading ridges 16, 17 employed in the present invention. It is seen that the stubs have a cross-sectional configuration in the X–Y plane which is equivalent to a conic-section.

The slow wave circuit of FIG. 2 provides good thermal dissipation characteristics and is considerably improved in this respect in comparison with non-supported or free space ring and bar slow-wave circuit. However, the stub supported ring and bar slow wave circuit of FIG. 2 has extremely degraded dispersion characteristics which result in very limited fixed beam voltage bandwidth. This is evidenced by examination of FIG. 5 wherein illustrative cold test dispersion characteristics of various ring and bar slow-wave circuits are depicted. The parameter $v_{p/c}$ is by definition the normalized phase velocity wherein v_p is the phase velocity of the R.F. energy and c is the speed of light while ka is defined as the circumference of the circuit ring having an average radius a divided by the free-space wavelength λo.

Thus

$$ka=\frac{2\pi a}{\lambda o}=\frac{2\pi fa}{c}$$

where

$$c=\lambda o^{f}$$

and

λo=free space wavelength. The selected range of operation is typically at a fixed beam operating voltage $.30<ka<.45$. The characteristics of FIGS. 5 and 6 were determined utilizing a ring and bar circuit having a periodic length of approximately $P=.037\lambda$, where λ=mid-band wavelength and a gap dimension g for the ridge loaded case of

$$\frac{1}{100}\lambda$$

with a ring thickness t in Z dimension of 1/6 P and a stub length l of 1/4 λu where λu=wavelength at upper end of the operating band.

The bandwidth of traveling wave tubes is largely determined by the dispersion characteristics of the slow wave circuit by virtue of the fact that beam and R.F. interaction or energy exchange occurs at approximate synchronism of the beam velocity and R.F. phase velocity. Thus for wide band operation it is extremely important to minimize dispersion.

Characteristic a in FIG. 5 depicts the dispersion characteristics of a non-supported or free space ring and bar circuit having the above indicated parameters. It is obvious that this circuit has a desirable dispersion characteristic and thus a relatively wide fixed beam voltage bandwidth. However, the extremely poor thermal dissipation characteristics of this circuit prevent useful operation thereof at high power levels. Examination of FIG. 6 shows that the K v. ka characteristic a for the free space ring and bar circuit provides adequate interaction impedance over the operating band.

Characteristic b in FIGS. 5 and 6 represents the ring and bar circuit represented by a with the addition of 1/4 λu tapered stub supports as previously described with reference to FIGS. 1 and 3. It is apparent that the addition of the tapered stubs does degrade the dispersion properties of the circuit thereby causing a reduction in useful fixed voltage bandwidth but with less increase in energy storage in the immediate area of the circuit rings in comparison with a linear stub having equivalent thermal characteristics. However, considerable thermal advantages are derived from the addition of the tapered stubs as will be detailed later and as seen in FIG. 6 a substantial rise in interaction impedance over the operating band is realized by the addition of tapered stubs.

Characteristic c represents the stub supported ring and bar circuit represented by characteristic b with the addition of two loading ridges having gap

$$g\cong\frac{1}{100}\lambda$$

It is again apparent that a considerable improvement in the dispersion properties of the circuit is achieved by the addition of the loading ridges while simultaneously retaining all of the thermal dissipation properties of the tapered stub supported ring and bar circuit. Furthermore, characteristic c in FIG. 6 shows that only a slight loss in interaction impedance is encountered. Thus a slow wave circuit has been developed which retains practically all of the excellent dispersion and impedance properties of the free space ring and bar circuit and which additionally has thermal dissipation properties which are substantially improved over the ring and bar circuit supported on untapered stubs.

Characteristic b in FIGS. 5 and 6 also depicts a prior art ring and bar slow wave circuit using linear or non-tapered stub supports such as shown in FIG. 2 having root dimensions equivalent to the tapered version. The dispersion characteristics of the tapered and linear stubs having equivalent root dimensions are thus seen to be practically identical. Attempts to increase the thermal dissipation properties of the circuit of FIG. 2 by increasing the transverse thickness of the stubs 19 linearly in either the Z or Y dimensions result in extreme degradation of the dispersion properties of the circuit because of increased energy storage between the stubs. In order to equate the thermal dissipation properties of the circuits of FIGS. 2 and 3 it would be necessary to equate the transverse cross-sectional area of the stubs of FIG. 2 to the transverse cross-sectional area of the stubs of FIG. 3 using prior art techniques of increasing the Y or Z dimensions or both would result in intolerable dispersion which would drastically narrow the fixed voltage bandwidth of the circuit. The dispersion could be reduced to a certain extent by employing the techniques of the present invention, namely, the addition of loading ridges. However, the amount of loading needed to lower the dispersion to the level of a free space ring and bar circuit would drastically reduce the interaction impedance

and thus the gain-per-periodic-length so as to negate any thermal dissipation advantages.

The stubs are preferably a ¼λ at the upper end of the operating band. If the stubs were made shorter than a ¼λ at the upper end of the operating band the slow-wave circuit would become more dispersive in the operating band and if the stubs were made longer than a ¼λ at the upper end of the operating band then the slow wave circuit would suffer a loss in beam interaction impedance.

FIG. 4 depicts an alternative method of approximating the tapered stub supporting techniques of the present invention by using a stepped stub, **20**, configuration. The advantages of minimal energy storage at the ring gaps and in the immediate area thereof where the axial electric fields are highest are realized by the tapered stub configuration of FIG. 3 and are also realized by the stepped stub configuration of FIG. 4.

The curved faces **21** having constant gap spacing *g* of the loading ridge are advantageously employed to maximize the shunt capacity added to the slow-wave circuit while simultaneously minimizing voltage breakdown characteristics therebetween for any given value of shunt capacity added to the circuit.

A traveling wave tube utilizing the tapered support stubs and loading ridge of the present invention was constructed and easily dissipated 50 watts at each root portion **22** of the stubs using O.F.H.C. copper material. The dimensions employed were: stub apex angle $\theta=30°$; root dimension $r=.075''$; stub thickness $t'=.045''$; and radial length l of ¾". A temperature gradient of 400° F. along the radial length of the stub was measured with a continuous 50 watts of power being absorbed at each root. The apex angle $\theta=30°$ was found to be the optimum angle for minimizing degradation of dispersion while simultaneously maximizing the thermal dissipation properties of the slow wave structure.

A traveling wave tube employing the above-mentioned structural parameters for the tapered stubs while supporting a ridge loaded ring and bar circuit at S band can advantageously operate at R.F. outputs in the range of 5 kw. C.W. and 5–100 kw. pulsed.

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 high frequency electron discharge device comprising, an electron gun disposed at one end of a predetermined path for generating and directing an electron beam along said predetermined path, a collector structure disposed at the other end of said predetermined path for collecting said beam, a slow-wave circuit disposed along said predetermined path between said electron gun and said collector structure, said slow-wave circuit being adapted and arranged such that an energy exchange between the electron beam and radio-frequency energy propagating on said slow-wave circuit is achieved, said slow-wave circuit including a helix-derived ring and bar type structure having a plurality of spaced axially aligned rings disposed around said predetermined path, thereby forming a plurality of spaced interaction gaps therebetween, said rings being supported by a plurality of spaced stubs, each of said stubs fixedly joined to a heat sink at the one end thereof and fixedly joined to a pair of adjacent rings of said plurality of spaced rings at the other end thereof, and a loading ridge disposed along said ring and bar type structure and spaced therefrom, said stubs each having their central axis lying in a series of spaced parallel planes disposed normal to said predetermined path, said stubs having different transverse dimensions along the length of the stubs between said one end and said other end thereof.

2. The device as defined in claim 1 wherein said stubs have tapered dimensions along the length thereof.

3. The device as defined in claim 1 wherein said stubs are stepped along the length thereof thereby approximating a taper.

4. The device as defined in claim 1 wherein said loading ridge has the surface thereof opposing the plurality of spaced rings shaped such that said surface approximates the configuration of the opposing ring surfaces.

5. The device as defined in claim 2 wherein said tapered dimensions are linear, said linear taper defining a conic-section having an apex angle of approximately 30°.

6. A slow wave circuit for high frequency electron discharge devices comprising, a contra-wound helix derived slow-wave circuit positioned along and disposed about a predetermined line of circuit development thereby defining a central axis, a plurality of supporting stubs fixedly attached to said slow-wave circuit, said stubs each having their central longitudinal axis lying in a plurality of spaced parallel planes, said planes being disposed normal to said central axis, said stubs having different transverse dimensions along the length thereof and a loading ridge disposed along the length of and spaced from said slow-wave circuit.

7. The circuit defined by claim 6 wherein said stubs have tapered dimensions such that the minimum transverse dimension of said stubs occurs at the root of said stubs, said root being the end portion of said stubs which is attached to said slow wave circuit.

8. The circuit defined by claim 7 wherein said tapered dimensions are linear, said tapered dimensions defining a conic-section having an apex angle of approximately 30°.

9. The circuit defined by claim 6 wherein said stubs are dimensionally stepped along the length thereof, said dimensional steps approximating a linear taper.

10. The device as defined in claim 6 wherein said loading ridge has the surface thereof opposing the slow-wave circuit shaped such that said surface approximates the configuration of the opposing slow-wave circuit surface.

11. A high frequency electron discharge device comprising, a conductive waveguide defining X-Y-Z dimensional co-ordinates, a helix derived slow-wave circuit disposed within said waveguide and extending along the Z-dimension of said waveguide, a plurality of supporting stubs each having their central axis lying in spaced parallel planes defined by the X-Y co-ordinates and spaced along the Z-dimension, one end portion of said stubs being fixedly attached to said slow-wave circuit the other end portion of each of said stubs being fixedly attached to said waveguide, said stubs having different Y-dimensions along the X-dimension thereof and a loading ridge fixedly attached to said waveguide and extending along the Z-dimension thereof, said loading ridge having its central axis lying in the Y-Z co-ordinates of said waveguide.

12. The device of claim 11 wherein said stubs have tapered Y-dimensions along the X-dimension thereof.

13. The device of claim 12 wherein said stubs are dimensionally stepped in the Y-dimension thereof along the X-dimension thereof.

14. The device of claim 12 wherein said tapered Y-dimensions are linear, said tapered dimensions defining a conic-section having an apex angle of approximately 30°.

15. An electron discharge device having an electron gun, collector structure and a slow-wave circuit disposed along a predetermined line of circuit development, said slow-wave circuit comprising a helix derived slow-wave circuit positioned along and disposed about a predetermined line of circuit development thereby defining a central axis, a plurality of supporting stubs fixedly attached to said slow-wave circuit, said stubs each having their central longitudinal axis lying in a plurality of spaced parallel planes, said planes being disposed normal to said central axis, said stubs having differ-

ent transverse dimensions along the length thereof and a loading ridge disposed along the length of and spaced from said slow-wave circuit.

16. A high frequency electron discharge device comprising, an electron gun, helix derived slow-wave circuit and a collector structure disposed along a predetermined line of circuit development, a conductive waveguide disposed along said predetermined line of circuit development, said conductive waveguide defining X-Y-Z dimensional coordinates, said helix derived slow-wave circuit disposed within said waveguide and extending along the Z-dimension of said waveguide, a plurality of supporting stubs each having their central axis lying in spaced parallel planes defined by the X-Y co-ordinates and spaced along the Z-dimension, one end portion of said stubs being fixedly attached to said slow-wave circuit

the other end portion of each of said stubs being fixedly attached to said waveguide, said stubs having different Y-dimensions along the X-dimension thereof and a loading ridge fixedly attached to said waveguide and extending along the Z-dimension thereof, said loading ridge having its central axis lying in the Y-Z co-ordinates of said waveguide.

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