

May 5, 1959

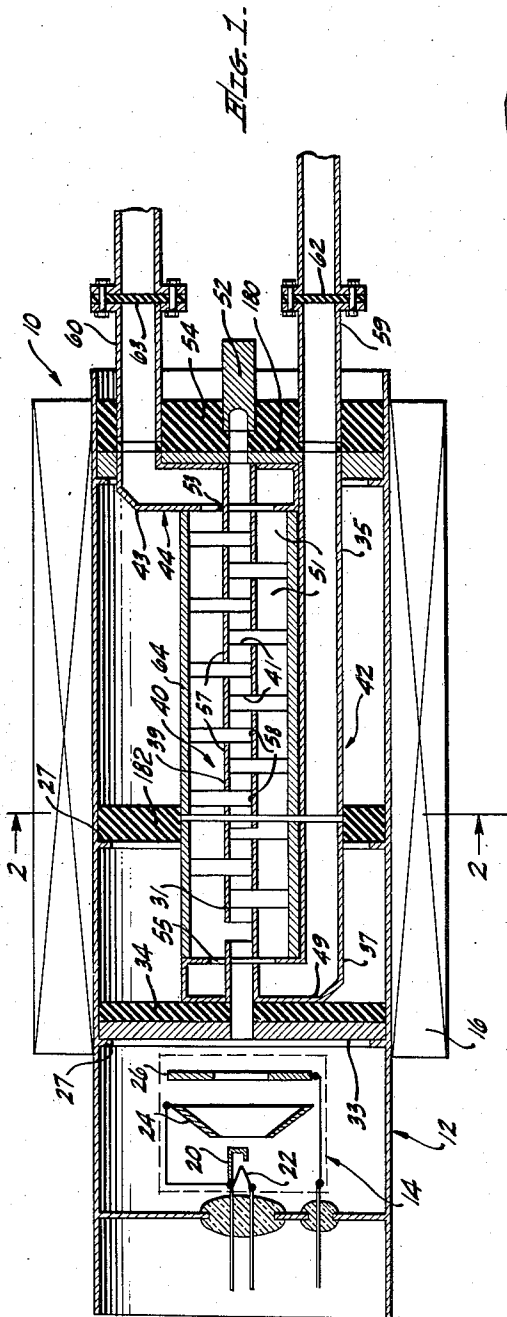
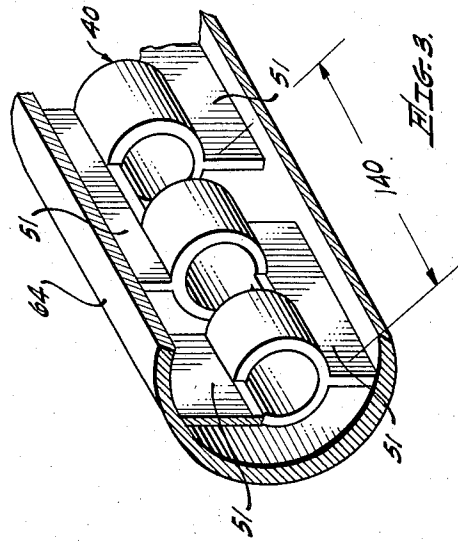
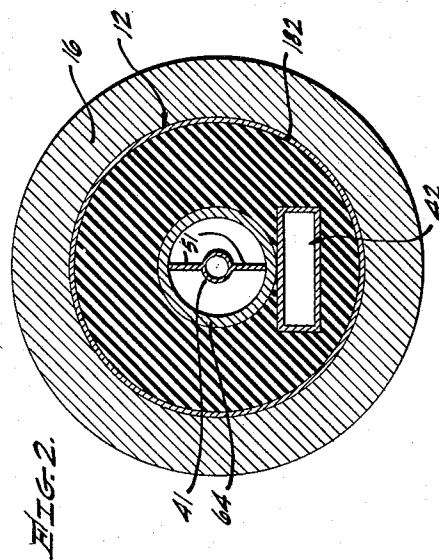
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2,885,641

MICROWAVE TUBE

Filed April 25, 1955

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

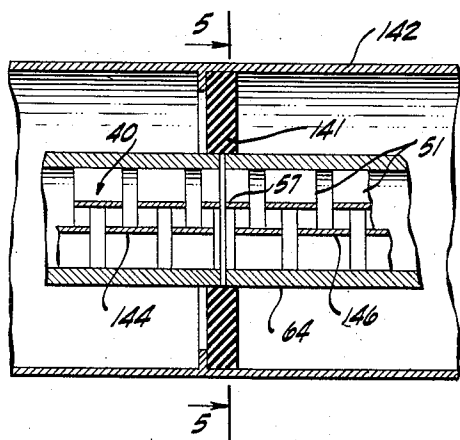


FIG. 4.

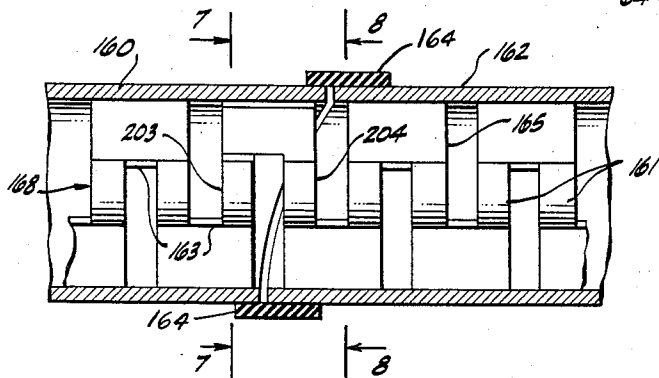


FIG. 6.

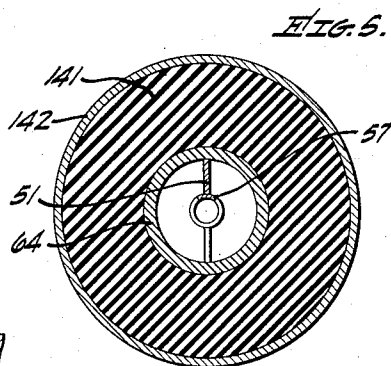


FIG. 5.

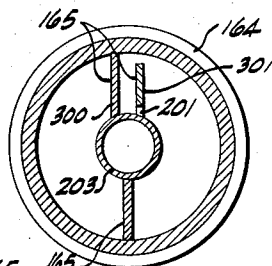


FIG. 7.

FIG. 8.

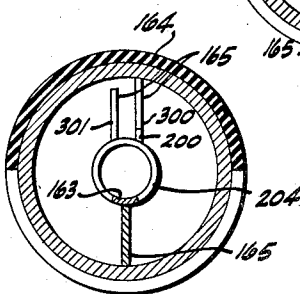
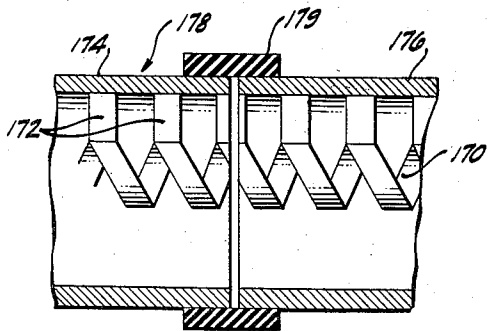


FIG. 9.



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2,885,641

MICROWAVE TUBE

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Application April 25, 1955, Serial No. 503,590

6 Claims. (Cl. 333—31)

This invention relates to electron tubes and more particularly to the slow-wave structure of a traveling-wave tube.

In a number of instances it has been found desirable to sever the slow-wave structure of a traveling-wave tube at one or more points along its length. For various reasons the separate sections of the slow-wave structure are electrically insulated and maintained at different direct-current potentials although an electromagnetic coupling is provided between them. Such slow-wave structures are described and claimed in copending application Serial No. 470,205, entitled "Traveling-Wave Tube Gain Control," filed November 18, 1954, by George R. Brewer and in copending application Serial No. 499,586, entitled Traveling-Wave Tube, filed April 6, 1955, by G. R. Brewer and C. K. Birdsall and assigned to the assignee of the present invention. In order to reduce useful radio-frequency energy loss in traveling-wave tubes employing a severed slow-wave structure, better coupling is needed for coupling electromagnetic energy from one of the separate sections of the slow-wave structure to an adjacent one. Ordinarily, the only coupling is the electron stream which is unsatisfactory in many applications.

It is therefore an object of the invention to provide improved means for coupling electromagnetic energy from one section of a severed slow-wave structure to an adjacent section.

It is another object of the invention to provide means for increasing the efficiency of a traveling-wave tube.

In accordance with the invention, radial conductors are connected from a slow-wave structure at the adjacent ends of two severed sections of a slow-wave structure in a manner to increase the electromagnetic capacitive coupling between the sections without interfering with the normal wave propagation characteristics of those sections.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

Fig. 1 is a sectional view of a traveling-wave tube employing the device of the present invention;

Fig. 2 is a transverse sectional view of the tube taken on the line 2—2 in Fig. 1;

Fig. 3 is a broken-away sectional view of the slow-wave structure of the traveling-wave tube of Fig. 1;

Fig. 4 is a broken-away sectional view of an alternative embodiment of the slow-wave structure of the present invention;

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Fig. 5 is a transverse sectional view of the slow-wave structure of Fig. 4 taken on the line 5—5;

Fig. 6 is a longitudinal sectional view of a modified slow-wave structure of the present invention;

Figs. 7 and 8 are transverse sectional views of the slow-wave structure of Fig. 6 taken on lines 7—7 and 8—8, respectively; and

Fig. 9 is a broken-away sectional view of still another embodiment of the present invention.

Referring to Fig. 1, a traveling-wave tube amplifier 10 is illustrated having a cylindrical, conductive, non-magnetic envelope 12 which may be made of copper. An electron gun 14 is sealed in the left extremity of the envelope, as viewed in Fig. 1. Electron gun 14 is employed to produce a stream of electrons and to direct it along the longitudinal axis of envelope 12.

A solenoid 16 is disposed concentrically about envelope 12 to provide an axial magnetic field along the electron stream path whereby the stream may be constrained along the complete length of the envelope. Such a field may be of the order of 600 to 1200 gauss.

Electron gun 14 essentially comprises a cathode 20, a heater 22, a focusing electrode 24, and an accelerating anode 26. The side of the heater connected to the cathode 20 is also connected to focusing electrode 24. Focusing electrode 24 has a frusto-conical shape with an internal surface of revolution forming an angle of 67½ degrees with its axis of symmetry.

A disc-shaped magnetic pole piece 33 and dielectric spacer 34 are disposed contiguously to an annular appendage 27 of the envelope 12. Within envelope 12, adjacent to and to the right of gun 14, as viewed in Fig. 1, a tortuous path slow-wave structure 40 is provided in electrical contact with and supported in part by a rectangular internal input waveguide segment 42 and a rectangular internal output waveguide segment 44. The slow-wave structure 40 and waveguide segments 42 and 44, which may consist of copper, may all be maintained at ground potential. Waveguide segments 42 and 44 are insulated from envelope 12 for purposes hereinafter set out. The internal input waveguide segment 42, for example, is divided into two insulated portions 35 and 37 which may be maintained at different direct-current potentials. The slow-wave structure 40 is likewise divided into two portions 39 and 31 which are, respectively, electrically and mechanically connected to waveguide portions 35 and 37.

Slow-wave structure 40 comprises a plurality of coaxial conductive rings 41, one set of adjacent pairs of rings being connected at one arcuate position 57 and the alternate set of pairs being connected to a portion 58 diametrically opposite portion 57. Waveguide segment 44 and portion 37 of waveguide segment 42 have transverse end portions 43 and 49, respectively, which have facing apertures 53 and 55, respectively, for launching a traveling-wave and for decoupling the wave at the output end of the slow-wave structure 40.

An external input waveguide segment 59 and an external output waveguide segment 60 are supported by suitable apertures in a disc-shaped dielectric spacer 54 which is disposed concentrically within the right end of envelope 12 adjacent a magnetic pole piece 180. Each of the external waveguide segments 59 and 60 are provided at their outer ends with mica "windows" 62 and 63, respectively, which provide vacuum seals. A vacuum may thus be maintained from the "windows" 62 and 63 to the opposite end of envelope 12 at the extreme left end of the envelope 12.

The stream electrons are intercepted by a collector electrode 52 at the opposite extremity of envelope 12 with respect to electron gun 14. Collector 52, which protrudes

outside of the envelope 12, is also supported by a suitable aperture in dielectric spacer 54 so as to have a surface external to the evacuated chamber for heat dissipation purposes. Accordingly, collector 52 is preferably fabricated of a metal having good electrical and heat conducting properties, as in the case of structure 40, such as, for example, copper.

A plurality of conductive fins or sheets 51 are electrically and mechanically connected lengthwise of and from slow-wave structure 40 to a conductive cylinder 64 which is disposed within the envelope 12. The conductive cylinder 64 is then mechanically and electrically connected to internal input waveguide segment 42. Such a slow-wave structure is described and claimed in copending applications Serial Nos. 456,682 and 490,088, both entitled "Traveling-Wave Tube," filed, respectively, September 16, 1954 and February 23, 1955. Both of these applications were filed jointly by C. K. Birdsall and L. M. Field and assigned to the assignee of the present invention.

One of the conductive fins 51 and a conductive ring 41 are shown to be severed or split in Fig. 1 in a plane transverse to the slow-wave structure 40. The conductive cylinder 64 and internal input waveguide segment 42 which is in electrical contact with conductive cylinder 64 are likewise severed in the same transverse plane in which the slow-wave structure 40 is split. A dielectric disc 182 is then positioned inside the envelope 12 to support the separate portions 39 and 31 of the slow-wave structure 40 and the conductive members connected thereto.

In Fig. 2 the split vertical fin 51 is shown connected to conductive cylinder 64 and the split conductive ring 41. Internal input waveguide segment 42 is shown in contact with conductive cylinder 64 which is supported by dielectric disc 182. The envelope 12 is then shown disposed about disc 182 and solenoid 16 is shown disposed about the envelope 12.

Fins 51 are shown to be in the same angular position in Fig. 1 although it is their axial positions or periodicity with respect to slow-wave structure 40 that makes them useful and not their particular arcuate positions. Each of the fins 51 has an arcuate thickness small in comparison to the external circumference of slow-wave structure 40 and extends axially over two of the cylinders 41 as shown in Fig. 1. Each of the fins may extend radially from the slow-wave structure 40 a distance equal to

$$\frac{n\lambda_0}{4}$$

where n is any positive odd integer and λ_0 is the free space wavelength corresponding to the mid-frequency of the operating band for which the tube 10 is designed. This requirement need not be critically followed, but it is desirable that the requirement be followed generally in order to avoid changing the impedance of the slow-wave structure at the mid-frequency of the tube operating band and to provide an alternating-current short circuit between the severed portion of the conductive ring 41 near the severed conductive fin 51. When the fins 51 extend an appropriate distance from slow-wave structure 40, a virtual shorting plane produced by conductive cylinder 64 will be prevented from appearing at the periphery of the slow-wave structure 40 between adjacent rings 41 to short electromagnetic energy therebetween. Wave propagation at the center of the operating frequency band will thus essentially be the same with or without the use of fins 51 although the fins are necessary to the electromagnetic coupling of the present invention.

Fig. 3 is a broken orthogonal view of slow-wave structure 40, fins 51 and conductive cylinder 64. Fins 51 are shown with a maximum axial length in order to provide a maximum heat conducting cross section. Fins 51 can be made much shorter axially, but they can be made no longer because the desirable wave propagation

properties of the slow-wave structure 50 would then be lost. The slow-wave structure 40 is deemed to simulate unifilar contrawound helices having a finite pitch equal to a dimension 140. This is described in detail in the applications of Birdsall and Field referred to above.

The applications of the slow-wave structures of the present invention to the type of tube disclosed and claimed in the sole application of Brewer and the joint application of Brewer and Birdsall, above referred to, are particularly advantageous because of the increased value of the axial shorting plane provided by conductive fins 51. It is obvious that the use of a split axially conductive segment 57 would decrease the area of the capacitive coupling from that provided by the cross-sectional area of a split conductive ring; however, an electromagnetic short circuit at one point is all that is needed at an axially conductive segment 57 and this alternative embodiment is shown in Figs. 4 and 5. A different dielectric disc 141 is there shown disposed within a conductive envelope 142 to support two portions 144 and 146 of the slow-wave structure 40 which is severed at an axially conductive segment 57. A split conductive fin 51 is also shown in both Figs. 4 and 5 with conductive cylinder 64. Here an open circuit at the end of the split, i.e. at cylinder 64, is reflected back to the inner end of the stub as a short so that the wave propagation is continuous across the split.

An alternative embodiment of the slow-wave structure of the present invention is shown in Fig. 6. Two conductive cylindrical portions 160 and 162 similar to conductive cylinder 64 are supported by a dielectric cylinder 164 which is also seen in Figs. 7 and 8. A slow-wave structure 168 is also shown in Fig. 6 comprising a plurality of conductive rings 161 and interconnecting axially conductive segments 163. A plurality of conductive fins 165 are then connected from the slow-wave structure 168 to the conductive cylindrical portions 160 and 162 in a manner analogous to the end connections of conductive fins 51.

In Figs. 7 and 8 it can be seen that the capacitive coupling between the insulated sections of the slow-wave structure 168 is increased because a large coupling area is provided by a split conductive fin 165 which has its two separate portions 300 and 301 separated. The electromagnetic coupling area is thus increased to the entire planar area of the split conductive fin 165. The split conductive fin 165 is divided into the two portions or slices 300 and 301 which have radially raised segments 200 and 201, respectively, on their respective lower edges. The raised portions 200 and 201 are thus insulated from two adjacent conductive rings 203 and 204, respectively, whereby the separate sections of the slow-wave structure 168 may be maintained at different direct-current potentials. An alternative viewpoint for explaining the operation of the structure of Figs. 6 to 8 is that split conductive fin 165 forms a transmission line about

$$\frac{\lambda_0}{4}$$

long which, at its outer end, nearest the outer cylinder, is electrically open so that a short circuit appears at its opposite end. This short causes the conductive fin 165 to appear electrically to be a solid unitary structure so that RF propagation is not affected by the actual separation in space of the two mechanically distinct portions of conductive fin 165.

In Fig. 9 a conventional type of conductive helix 170 for a traveling-wave tube is illustrated having a plurality of radially conductive fins 172 connected from the conductive helix 170 to two portions 174 and 176 of a conductive cylinder 178. A dielectric cylinder 179 supports the mutually adjacent ends of conductive cylinder 178.

In traveling-wave tubes employing unifilar and multifilar conductive helices, backward wave self-oscillations are troublesome. About the backward wave self-oscil-

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lation band, the practical operation of a traveling-wave tube solely as an amplifier is impossible. Conductive fins 172 may thus be employed to achieve two objectives. Firstly, conductive fins 172 may in addition be employed to provide a stop band at the backward wave self-oscillation band of frequencies for the helix 170. Secondly, an improved electromagnetic coupling across a break may be provided.

It is well known that periodic discontinuities along a waveguide structure, such as the fins 51 along the slow-wave structure 40, provide stop bands when they occur at a spacing, L , or interval equal to

$$\frac{m}{2}\lambda_g$$

where λ_g is the unloaded waveguide wavelength of the stop band mid-frequency and m is any positive integer. The angular alignment of the conductive fins shown in Fig. 1 is, of course, unnecessary but a certain spacing relationship should be maintained to provide backward wave stop bands. This spacing is

$$d = \frac{m}{2}\lambda_g$$

where d is the axial distance between the conductive fins 172. The radial length of the conductive fins 172 may be

$$\frac{n}{4}\lambda_0$$

in accordance with the rule of design set down with respect to the radial length of the conductive fins 51 shown in Fig. 1. The axial length of conductive fins 172 may be equal to the width of the tape forming the helix 170. This is analogous to the case of the axial length of the conductive fins 51 which have an axial dimension equal to the axially conductive length of the specified portions of the slow-wave structure 40 to which fins 51 are connected, i.e. equal to the sum of the width of two of the conductive rings 41 and the length of an axially conductive segment connecting two adjacent rings 41.

By the use of any of the embodiments of the device of the present invention stop bands may be provided or avoided as desired and an improved electromagnetic coupling may be provided between two sections of a slow-wave structure which are electrically insulated without materially reducing the slow-wave structure forward wave impedance or its impedance to waves within its operating frequency band.

What is claimed is:

1. A wave-type amplifier comprising a conductive tortuous path slow-wave structure for propagating electromagnetic waves, means providing axially periodic discontinuities along the slow-wave structure comprising a plurality of conductors having axial lengths and extending radially outwardly from and connected to the slow-wave structure at predetermined intervals therealong, the slow-wave structure and said conductors being severed at at least one point along the length of said slow-wave structure such that the resulting segments are capacitively coupled for purposes of propagating said electromagnetic waves while providing direct-current insulation between the severed segments.

2. A wave-type amplifier comprising a conductive tortuous path slow-wave structure comprising predetermined periodic elements for propagating electromagnetic waves, means providing axially periodic discontinuities along the slow-wave structure comprising a plurality of conductors having axial lengths and extending radially outwardly from and connected to the slow-wave structure at predetermined intervals therealong, the slow-wave structure and one of said conductors being severed at at least one point along the length of the slow-wave structure such that the resulting segments are capacitively coupled for purposes of propagating said electromagnetic waves while

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providing direct-current insulation between the severed segments, and at least two separate enveloping cylindrical conductive members insulated from each other connecting the outer extremities of said conductors disposed on the respective severed portions of the slow-wave structure, the combination of said conductors and said enveloping cylindrical conductive members being adapted to reflect open circuit impedances between predetermined elements of said slow-wave structure while providing thermal conductivity and mechanical support thereto.

3. The invention as defined in claim 2, wherein said enveloping cylindrical conductive members are spaced

$$\frac{n}{4}\lambda_0$$

from the slow-wave structure, where n is any positive odd integer, and λ_0 is the free space wavelength of the mid-frequency of the operating band of said amplifier.

4. The invention as defined in claim 2, wherein said predetermined intervals are equal to

$$\frac{m}{2}\lambda_g$$

where m is any positive integer and λ_g is the unloaded waveguide wavelength of the mid-frequency of the backward wave self-oscillation band of the slow-wave structure.

5. A tortuous path slow-wave structure comprising, in a first and second set a plurality of successively spaced conductive rings having their apertures disposed in register and in electromagnetic coupling interrelation with each other forming a unitary operative slow-wave structure, said first set including alternate ones of said plurality, said second set including the alternate ones of said plurality adjacent the ones of said first set, a first set of axially straight conductive segments connected between each adjacent pair of the first set of said conductive rings at a first point about said conductive rings, a second set of axially straight conductive segments connected between each adjacent pair of the alternate and second set of said conductive rings at a second point diametrically opposite said first point about said conductive rings, and a first and second set of conductive sheets connected respectively to said first and second sets of adjacent pairs of said conductive rings at the position of said first and second sets, respectively, of said axially conductive segments connecting each of said pairs of conductive rings, at least one of said conductive rings and the conductive sheet connected thereto being severed, said severed conductive sheet after being severed providing a capacitive electromagnetic coupling between the resulting segments of said slow-wave structure while at the same time providing direct-current insulation therebetween.

6. A tortuous path slow-wave structure comprising, in a first and a second set, a plurality of successively spaced conductive rings having their apertures disposed in register and in electromagnetic coupling interrelation with each other forming thereby a unitary operative slow-wave structure, said first set including alternate ones of said plurality, said second set including the adjacent alternate ones of said plurality, a first set of axially straight conductive segments, respective ones of said segments being connected between each adjacent pair of said first set of said conductive rings at a first point about said conductive rings and a second set of axially straight conductive segments, respective ones of said segments being connected between each adjacent pair of said second and alternate set of said conductive rings at a second point diametrically opposite said first point about said conductive rings, and first and second sets of conductive sheets connected, respectively, to said first and second sets of conductive rings at the axially conductive segments connecting each of the adjacent pairs of said conductive rings, one of said axially conductive segments being removed, and that conductive sheet which would otherwise

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be connected to said removed axially conductive segment being sliced along an axial-radial plane, each of the two resulting slices of said sliced conductive sheet being severed from different ones of the two said conductive rings to which said removed axially conductive segment was connected so that the slices remain connected respectively to different ones of said two conductive rings, said sliced conductive sheet providing thereby a capacitive

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electromagnetic coupling between the severed portions of said slow-wave structure.

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