Jan. 19, 1960 R. M. VAN DIEN 2,922,067

HIGH FREQUENCY ENERGY INTERCHANGE DEVICE

Filed Oct. 29, 1958 2 Sheets-Sheet 1

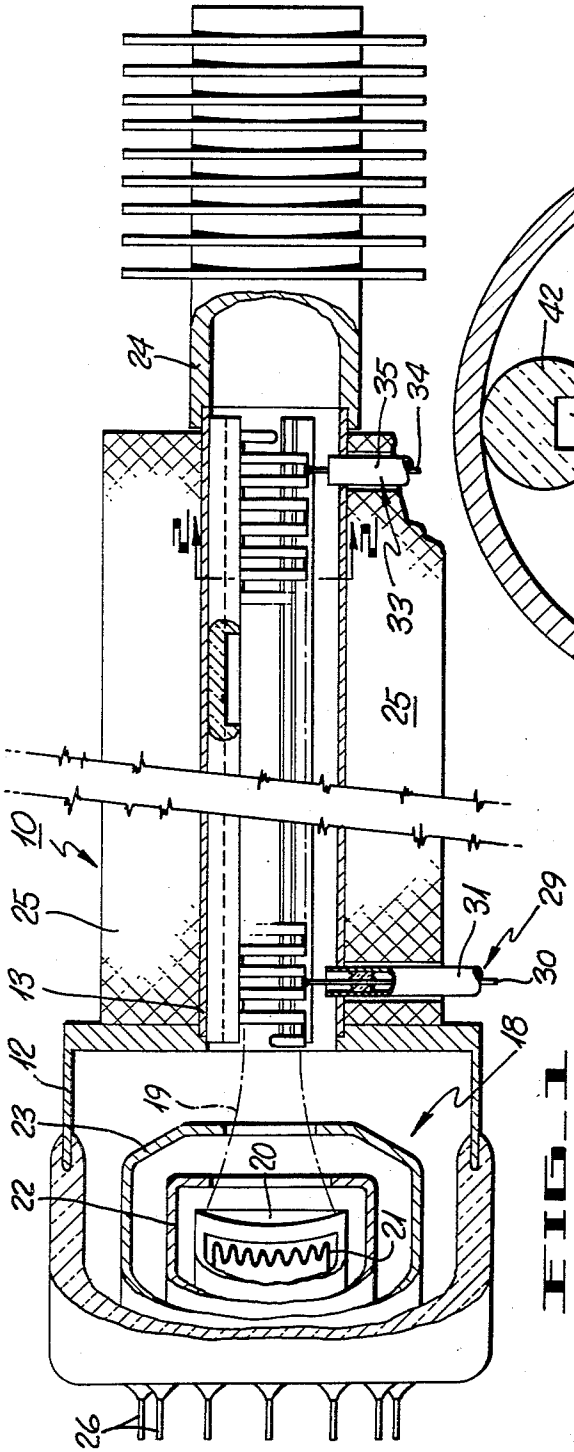


FIG. 1

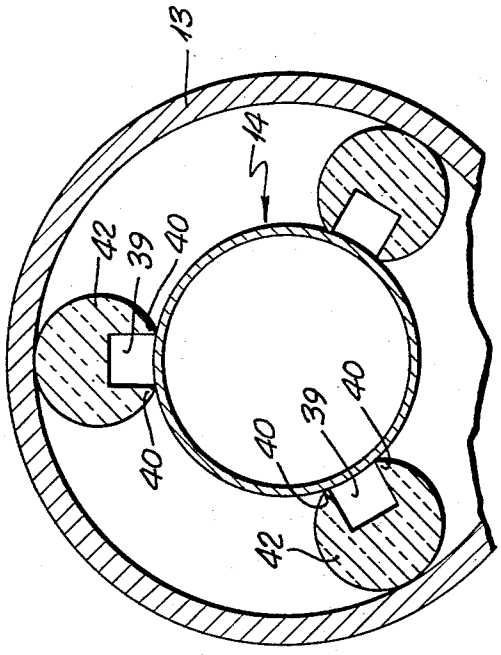


FIG. 2

ROLAND M. VANDIEN
INVENTOR.

BY Urban L. Faulkner

ATTORNEY

Jan. 19, 1960 R. M. VAN DIEN 2,922,067

HIGH FREQUENCY ENERGY INTERCHANGE DEVICE

Filed Oct. 29, 1958 2 Sheets-Sheet 2

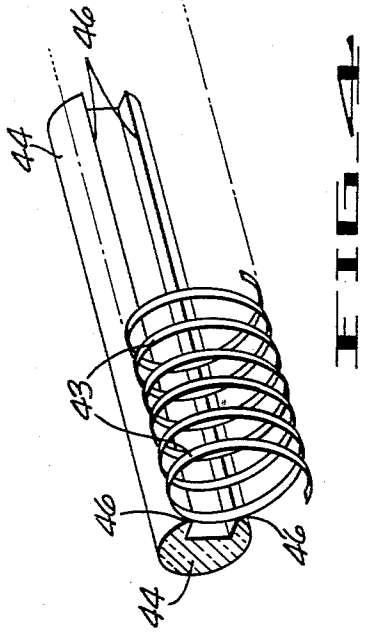


FIG. 4

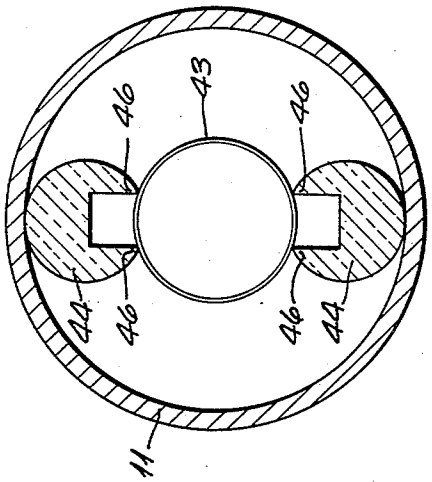


FIG. 6

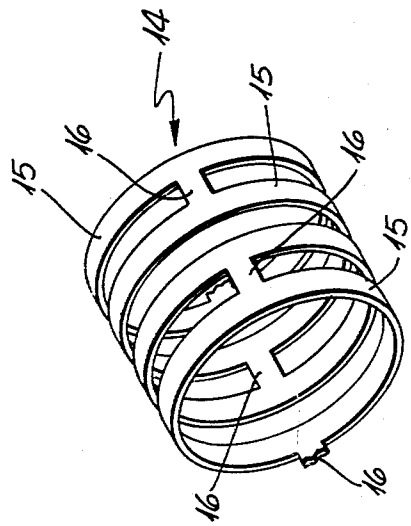


FIG. 3

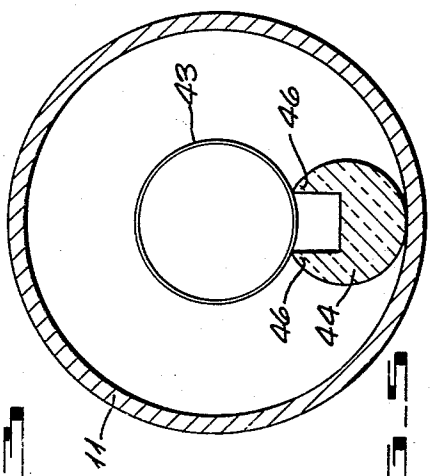


FIG. 5

ROLAND M. VAN DIEN
INVENTOR.

BY Urban L. Faubion

ATTORNEY

United States Patent Office 2,922,067 Patented Jan. 19, 1960

2,922,067

HIGH FREQUENCY ENERGY INTERCHANGE DEVICE

Roland M. Van Dien, Menlo Park, Calif., assignor to General Electric Company, a corporation of New York

Application October 29, 1958, Serial No. 770,367

3 Claims. (Cl. 315—3.5)

This invention relates to high frequency energy interchange devices wherein the interchange of energy takes place between a stream of electrons and a radio frequency field to provide amplification and/or oscillations. More particularly, the invention relates to the class of high frequency energy interchange devices known as traveling-wave tubes, which include an electron gun for producing a stream of electrons in an interaction region and a radio frequency circuit or transmission line for producing radio frequency fields in the region of interaction; and the invention has for one of its principal objects the provision of attenuators for such devices which allow improved performance and simplification of design and construction.

The present invention is particularly applicable to traveling-wave tubes which utilize a slow-wave radio frequency circuit of the helix or helix-derived type. It is intended that each of the terms "helix" (or "helical") and "helix-derived" be applied to radio frequency slow-wave transmission lines in the manner commonly used in the traveling-wave tube art. For example, the terms encompass wire and tape helices of the single and multifilar varieties and the cross-wound or contra-wound structures. The terms also encompass the circuit of the so-called ring-bar types. Such helix and helix-derived slow-wave circuits are illustrated and described in many texts and articles. For example, see M. Chodorow and E. L. Chu, "Cross-Wound Twin Helices for Traveling-Wave Tubes," Journal of Applied Physics, vol. 26, pp. 33–34, January 1955; Samuel Sensiper, "Electromagnetic Wave Propagation on Helical Structures," Proceedings of the IRE, vol. 43, pp. 149–161, February 1955; and C. K. Birdsall and T. E. Everhart, "Modified Contra-Wound Helix Circuits for High-Power Traveling-Wave Tubes," IRE Transactions on Electron Devices, vol. ED–3, No. 4, pp. 190–204, October 1956.

It is very important in traveling-wave tubes using helical slow-wave circuits that the helix be supported firmly and accurately in predetermined position with respect to the electron stream and the external radio frequency circuit elements. In addition, when there is appreciable power flowing down the helix, or when there is some interception of the electron stream by the circuit, a means of dissipating heat produced in the helix turns must be provided. Commonly, both the mechanical support and heat-dissipating requirements are met by supporting the helix on one or more rods of a dielectric material such as synthetic sapphire having high mechanical strength and a high thermal conductivity. This arrangement however, is not acceptable in all situations and is undesirable for most situations since the electrical performance (rate of gain, efficiency, etc.) of the helix as a circuit element is degraded by the presence of the support rods. That is to say that the portion of the dielectric support rods between each pair of turns of the helix is effectively a capacitance connected between the turns which reduces the impedance of the helix and consequently reduces the effectiveness of the helix in producing

an interaction between electromagnetic waves propagated therealong and electrons in an electron stream in interacting relationship with the electromagnetic waves. This effect of the dielectric rods is called "dielectric loading." Accordingly, it is an object of the present invention to provide a sound and accurate means for mounting the helix in a traveling-wave tube which is also capable of dissipating heat without seriously degrading the operation of the helix by contributing to the dielectric loading.

Attempts to solve the problem outlined above have included the use of very small solid rods having a low dielectric constant to support the helix in a traveling-wave tube. Such a solution has not proved to be satisfactory principally due to the heat transfer problem. The side of the supporting rods away from the helical circuit must be in thermal contact with a mass of high heat conductivity such as a metallic block or envelope. Since the metallic surface cannot be placed close to the helix for electrical reasons, there is a minimum acceptable support rod diameter. Furthermore, in choosing the dielectric constant of the support rod, one is limited to material having relatively high thermal conductivities. For example, the most obvious choice is synthetic sapphire which has a relatively high dielectric constant

$$\left(\frac{\epsilon}{\epsilon_0}\right)=9.6$$

where ϵ permittivity and ϵ_0 is the permittivity of free space).

Accordingly, it is a further object of this invention to provide a support structure for the helix of a traveling-wave tube which meets the mechanical and heat dissipating requirements and which does not necessitate making the traveling-wave tube excessively long in order to compensate for dielectric loading due to the support.

In carrying out the objects of the present invention, a traveling-wave tube is provided which has a slow-wave structure of a helical or helix-derived form and one or more support members for the slow-wave structure which support members for the slow-wave structure are contoured to present essentially a line contact down the length of the entire slow-wave structure.

The novel features which are believed to be characteristic of the invention are set forth in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Figure 1 is a broken and partially broken away side elevation of a high frequency energy interchange device embodying the present invention;

Figure 2 is a transverse section through the tubular body portion of the device of Figure 1 taken on line 2—2 of Figure 1;

Figure 3 is a perspective view of a segment of the slow-wave transmission line used in the device of Figure 1;

Figure 4 is a perspective view of another type of helical slow-wave structure and its support which may be utilized with the traveling-wave tube illustrated in Figures 1 and 2;

Figure 5 is a transverse section through the tubular body of a traveling-wave tube illustrating how the helix and helix support of Figure 4 may be positioned within the tubular body; and

Figure 6 is a transverse section through the tubular body of a traveling-wave tube similar to that of Figure 5 illustrating another means of using the helix supports of the present invention to support a helix in the tubular body of a traveling-wave tube.

In Figure 1 of the drawings, a traveling-wave tube 10 is illustrated. Traveling-wave tube 10 is provided with an envelope 11 which is generally long and cylindrical.

As illustrated, the envelope **11** has an enlarged cylindrical glass and metal portion **12** at one end and a smaller longer metallic cylindrical portion **13** forming the opposite end. The enlarged cyclindrical portion **12** houses an electron stream producing gun **18** and the small slender cylindrical portion **13** houses the long helical main interaction transmission line **14**. Thus the two principal interaction producing elements are enclosed in the envelope **11**. That is, electrons are projected down the length of the slow-wave circuit **14** by electron gun **18** in such a manner that they interact with eletromagnetic waves propagated down the slow-wave transmission line **14** to produce amplification. This phenomonon is described in more detail below.

The metal and glass portions of the electron gun enclosing bulb **12** are sealed to form a unitary enclosure which will hold a vacuum. The metal front end of the gun enclosing bulb **12** is positioned coaxially with respect to the metal helix enclosing cylindrical portion **13** of the vacuum tube such as by brazing. The particular main transmission line **14** illustrated (best seen in Figures 1 and 3) is one of the helix-derived slow-wave circuits which is a contra-wound helix of the type known as a ring-bar structure. The particular type of transmission line is called helix-derived since it does not conform to the strict technical definition of a helix and yet is a circuit which performs (electrically) like a contra-wound helix. The ring-bar circuit is formed by a series of identical coaxial rings **15** which are spaced apart in the axial direction. Each of the rings **15** is joined to the next succeeding ring with short bars **16** and each bar **16** is spaced around the periphery of the pair of rings **15** which it links 180° with respect to the preceeding bar **16**. The length of bars **16** is determined by the velocity of the electron stream and the frequency of the radio frequency wave in accordance with well known traveling-wave tube helix-design principles as set forth in "Traveling-Wave Tubes" by J. R. Pierce, Van Nostrand Company, Inc., New York, 1950. The principles of the invention are applicable to any type of helical slow-wave structure but the ring-and-bar structure is illustrated to show one particular form of the invention.

A stream of electrons is produced and projected along the axis of the envelope **11** by the electron gun **18** as depicted by the broken lines **19** in Figure 1. The electrons which are formed into a stream are emitted from a cathode **20** in response to heat applied thereto by a heater member **21**. As illustrated, the heater member **21** is a high resistance coil located near the emitting cathode button **20**. The stream **19** is formed and projected along the longitudinal axis of the tube by a centrally apertured electron stream focusing electrode **22** and a centrally apertured electron stream accelerating anode **23**. Since the elongated main slow-wave transmission line **14** is positioned inside the slender portion **13** of the envelope with its axis coincident with the tube axis, the electron stream **19** is projected down the length of the tube in close proximity thereto, thus providing an interaction region along the axis of the tube. A collector anode **24** is positioned at the opposite or output end of the structure to dissipate residual energy in the stream. The collector anode **24** is provided with a series of annular cooling fins **26** thereabout.

In order to prevent the space charge of the electrons from spreading them to such an extent that they pass out of the interaction region and intercept the slow-wave transmission line **14**, it is necessary to provide some focusing means. Focusing is provided in the device illustrated by producing a magnetic field axially along the structure. This is typically done by providing a long annular solenoid **25** which surrounds the entire tube along its length. To simplify the present drawing and description, the magnetic field producing solenoid **25** is only partially and schematically illustrated and its source of energizing potential is not shown. Further, the operating power source for the tube **10** is not shown since it is conventional and does not form a part of the present invention. The potentials on the electrodes of the electron gun are established by means of conductive leads or pins **26** which are brought out through the base **12** of the tube **10**. The relative potentials applied to the various electrodes are established in accordance with well known gun design considerations (see J. R. Pierce "Theory and Design of Electron Beams," 2nd edition, 1954, Van Nostrand Co.).

A desired radio frequency electromagnetic wave is coupled or transferred onto the slow-wave transmission line **14** by a coaxial transmission line **29** in such a manner that the transferred wave is propagated from the gun end of the tube toward the output or collector end. In order to accomplish this, the inner conductor **30** of the coaxial transmission line **29** is brought into the envelope **11** near the gun end of the tube and electrically connected with a bar **16** (cross-over point of two rings of the slow-wave transmission line **14**), and the outer conductor **31** is connected to ground or reference potential. In the embodiment illustrated, the outer conductor **31** is connected to the cylindrical metal helix enclosure **13**. Since the coaxial transmission line **29** is brought into the vacuum tube through the outer wall, a dielectric vacuum tight seal or window **32** is provided between the inner and outer conductors to prevent tube leakage.

Radio frequency energy is abstracted from the tube **10** near the collector end by an output coaxial transmission line **33** which also extends out through the metal helix enclosure **13**. The output coaxial transmission line **33** also has an inner conductor **34** which makes contact with a bar **16** or cross-over point of two rings **15** and an outer conductor or cable sheath **35** connected to the metallic helix enclosure **13** which is at ground or reference potential. Once again it is necessary to provide a dielectric seal or window between the inner and outer conductors **34** and **35** in order to prevent tube leakage. The details of the output connections and window are not shown since they are identical to the connection and window **32** for input transmission line **29**.

The apparatus described thus far provides conventional traveling-wave interaction and the particular apparatus illustrated acts as an amplifier. That is to say, the electromagnetic waves introduced onto the helix **14** by the input transmission line **29** interact with the electrons in the electron stream **19** to produce electron velocity modulation and consequently electron bunching. As the wave and stream travel along the length of the slow-wave transmission line **14**, the phenomenon reverses and the bunched stream induces fields and currents along the helix. The amplitude of the wave on the helix **14** grows exponentially until the stream becomes saturated because the stream gives up more energy to the helix **14** than it abstracts from it. However, it is apparent that the interaction cannot take place in an efficient manner unless the helical winding **14** is firmly and accurately supported in coaxial alignment with the electron stream. In the apparatus illustrated in Figures 1 and 2, a sound mounting for the helix **14** is provided by three heat conductive and electrically non-conducting dielectric support rods **42**, preferably a synthetic sapphire, spaced equidistant around the periphery and extending the full length of transmission line **14**. The side of each rod **42** which is in contact with the helix **14** is contoured or provided with a slot **39** down its full length. In this manner, contact between each support rod **42** and the helix **14** is essentially a line contact on two spaced apart lines defined by the two knife edges **40** formed by the slot **39**. In other words, each helix turn is supported by each rod **42** at two points where it contacts the edges of the slot **39**.

The slot **39** in each support rod **42** is purposely made deep enough that its bottom is in a region where radio frequency electric fields established on the helix **14** are low in amplitude. Thus, only a small portion of the dielectric, that part on either side of the slot **39**, is in

the region where the electric fields are high in amplitude. The practical result of this arrangement is that an absolute minimum of dielectric loading of the helix **14** is provided by the support rods **42** and consequently an absolute minimum of degradation in performance of the helical circuit results. The helix turns may be brazed to the support rods **42** although it is not necessary with the arrangement illustrated in Figures 1 and 2.

The outer sides of the support rods **42** are in intimate contact with the inner surface of the metallic envelope **11** and thus provide the necessary support for the helix **14**. This arrangement also provides excellent cooling for the helix, since the sapphire support rods **42** are good heat conductors and the metallic envelope **11** acts as a heat sink. Heat conduction between the support rods **42** and metallic envelope **11** can be improved somewhat by flattening the outer sides of the rods to enlarge the area of contact between the envelope **11** and rods **39** but this is not usually necessary. Also, the sapphire rods **42** may be brazed to the inner surface of the envelope **11** to provide additional rigidity.

Figure 4 illustrates one means of supporting a tape helical slow-wave transmission line **43** with a contoured support rod **44** in a manner similar to that illustrated in connection with the ring-bar cross wound helix **14** of Figures 1, 2 and 3. As illustrated in Figure 4, the contoured support rod **44** is circular in cross section with a rectangular slot **45** milled out along its entire length so that two knife edges **46** are formed along the length of the rod. The tape helix **43** then is positioned with one side in the milled-out slot in such a manner that each helix turn is supported at two points where it contacts the edges **46** of the slot.

Figure 5 illustrates the way in which the tape helix **43** may be supported within a tube envelope **11** by the single support rod **44**. In the embodiment illustrated, the turns of the helix **43** are brazed to the knife edges **46** on the support rod at their point of contact and the outer edge or periphery of the support rod **44** is brazed along the inner periphery of the metallic envelope **11** in such a manner as to hold the tape helix **43** in a properly aligned position.

Obviously the tape helix **43** may be held in position in the envelope **11** by supporting it between three support rods spaced equidistant around its periphery in a fashion similar to the way in which the support rods **42** support the ring-bar helix **14** (best seen in Figure 2). Such an arrangement does not require brazing of the helix **43** to the support rods **44** or the support rods **44** to the envelope **11**. Further, the number of support rods **44** utilized is not crucial to the invention. For example, two support rods **44** may be placed on opposite sides of the tape helix **43** so that the helix is trapped between four opposing knife edges **46** and this assembly may be inserted in an envelope **11** in such a manner as to form a snug fit within the envelope. Such an arrangement is illustrated in Figure 6.

The arrangements illustrated show a means of supporting a helix slow-wave circuit of a traveling-wave tube which provides the desired mechanical positioning and rigidity of the helix, excellent cooling of the slow-wave structure, and a very minimum of degradation of performance due to dielectric loading. The extent to which the electrical performance of the helix is improved due to the use of the contoured support rods illustrated is indicated by the curves of Figure 7.

A comparison of the dielectric loading factors for a tape helix in free space and for a tape helix supported on contoured and un-contoured support rods gives an accurate indication of the improvement in helix performance due to the use of support rods which are contoured in accordance with the present invention. The dielectric loading factor (DLF) is effectively a measure of the reduction in field strength of an actual helix from that of a sheath helix due to space harmonic content and dielectric loading of the helix. For one tape helix of the type illustrated in Figure 4, the dielectric loading factor in free space was found to be 0.86; brazed on an uncontoured sapphire rod, the dielectric loading factor was found to be 0.65; and brazed on a contoured rod, the dielectric loading factor was 0.76.

As reported by P. K. Tien in an article entitled "Traveling-Wave Tube Helix Impedance," Proceedings of the IRE, vol. 41, pp. 1617–1623, November 1953, the interaction impedance of a helix is approximately proportional to the square of the DLF. Thus, a given helix brazed to a contoured sapphire support rod has an impedance of $(0.76)^2Z$ or $0.5776Z$ where Z is the impedance of a sheath helix of corresponding size and phase velocity in free space as compared with an impedance $(0.65)^2Z$ or $0.4225Z$ for the same helix brazed to a solid sapphire rod. Thus, a given helix brazed to a slotted sapphire support rod has a considerably higher impedance than one brazed to a solid rod. Since the gain per unit length for a helix in a traveling-wave tube with a given electron stream is determined by the impedance of the helix, it is apparent that the performance of a helix brazed to a contoured sapphire rod as illustrated in Figure 4 is much better than that of a helix brazed to a solid sapphire rod or a helix which is enclosed by dielectric material. In addition to the electrical superiority of the contoured support rod **42** over the uncontoured counterpart, the contoured rod provides a secure and accurate mounting for the helix and a good means of removing heat from the helix.

While particular embodiments of the invention have been shown, it will, of course, be understood that the invention is not limited thereto since many modifications, both in the circuit arrangements and in the instrumentalities employed, may be made. It is contemplated that the appended claims will cover any such modifications as fall within the true spirit and scope of the invention.

What I claim is new and desire to secure by Letters Patent of the United States is:

1. A traveling-wave tube comprising an elongated evacuated envelope containing a source of electrons adapted to project a stream of electrons along the longitudinal axis of said envelope, a helical slow-wave transmission line positioned coaxially with the longitudinal axis of said envelope, and at least one elongated insulating support rod positioned adjacent an inner wall of said envelope, said elongated rod being of heat conductive dielectric material contoured to provide a depressed portion and a pair of edges extending longitudinally of said rod, said edges being spaced apart to receive and support said helical transmission line at two points on each turn and the contour of said rod being such that the depressed portion is remote from high amplitude electric fields from said transmission line.

2. In combination in a traveling-wave tube having an elongated evacuated envelope, means to form and direct a stream of charged particles down the length of the envelope, a helical slow-wave transmission line positioned coaxially with said elongated envelope, and at least one elongated insulating support rod of circular cross section positioned adjacent the inner wall of the envelope, said elongated rod being of heat conductive dielectric material and provided with a longitudinally extending groove diametrically opposite the line of contact with the envelope wall defining a pair of spaced apart helix supporting edges which receive and support said helical transmission line and a bottom portion sufficiently removed from said supporting edges to insure that electric fields along said slow-wave transmission line are low in amplitude in the region of the dielectric material along the bottom portion of the groove in said rod.

3. A traveling-wave tube comprising an elongated evacuated envelope containing a source of electrons adapted to project a stream of electrons along the longitudinal axis of said envelope, a helical slow-wave transmission

line positioned coaxially with the longitudinal axis of said envelope, and two or more elongated insulating support rods positioned adjacent inner walls of said envelope, said elongated rods being of heat conductive dielectric material contoured to provide a depressed portion and a pair of edges extending longitudinally of each of said rods, said edges being spaced apart to receive and support said helical transmission line at two points on each turn and the contour of said rod being such that the depressed portion is remote from high amplitude electric fields from said transmission line, said insulating support rods being positioned around the inner wall of said envelope to hold said helical transmission line in compression therebetween.

References Cited in the file of this patent

UNITED STATES PATENTS

1,616,184	Griffith	Feb. 1, 1927
1,720,443	Robinson	July 9, 1929
2,812,499	Robertson	Nov. 5, 1957