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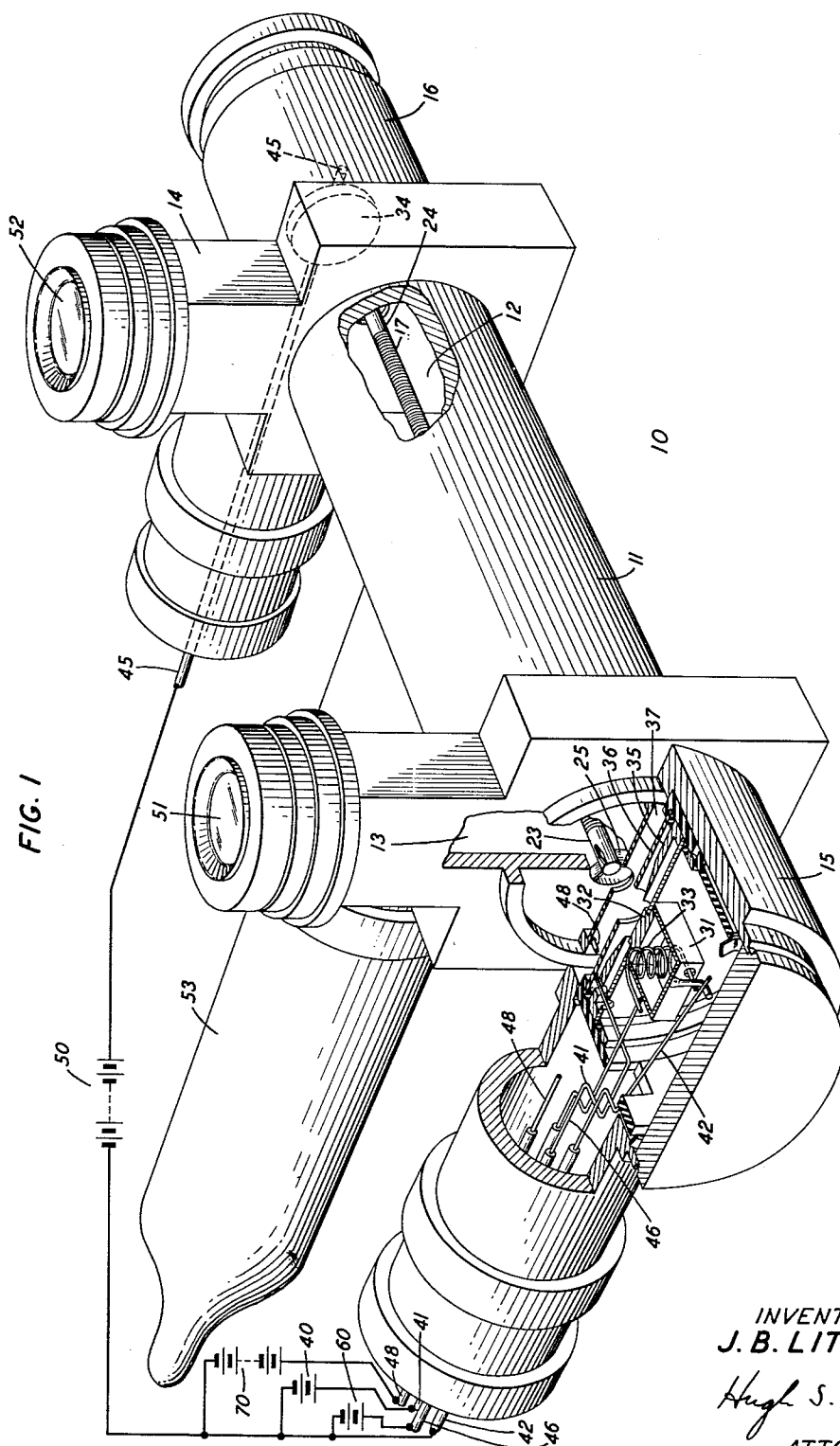
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2,716,202

MICROWAVE AMPLIFIER ELECTRON DISCHARGE DEVICE

Filed June 20, 1950

2 Sheets-Sheet 1



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MICROWAVE AMPLIFIER ELECTRON DISCHARGE DEVICE

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2 Sheets-Sheet 2

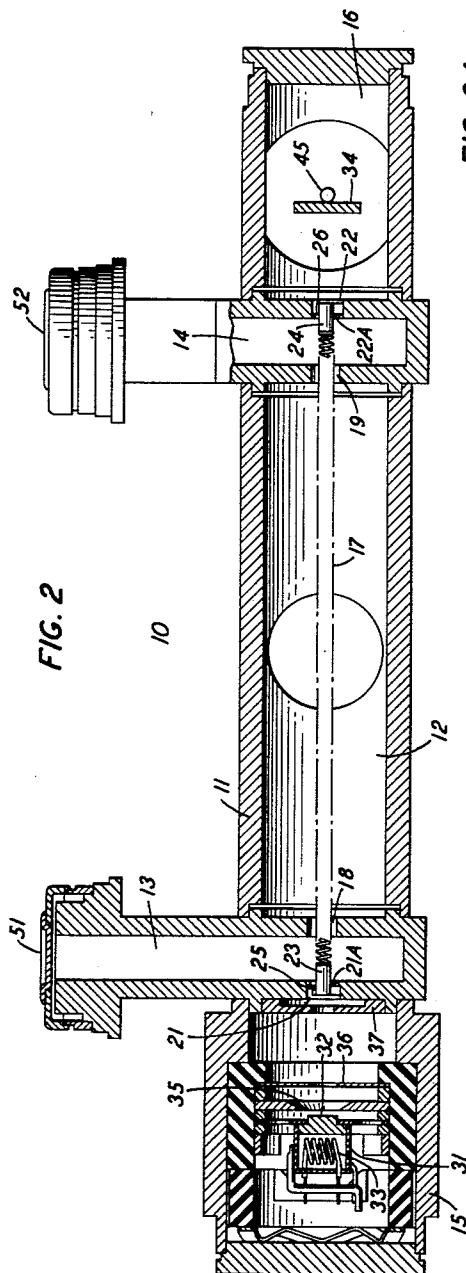


FIG. 2

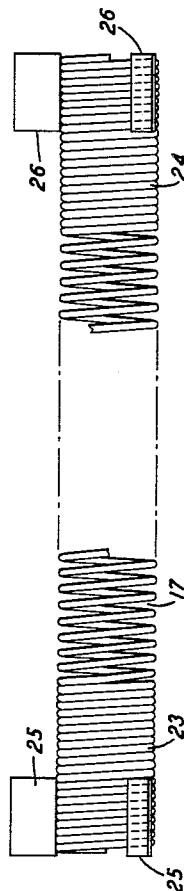
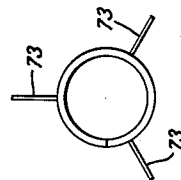
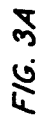
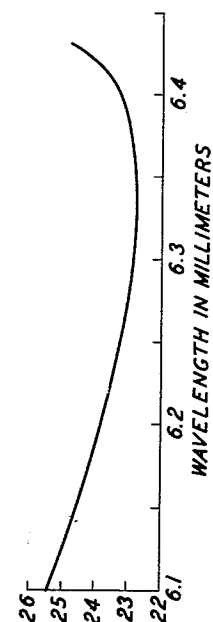
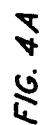
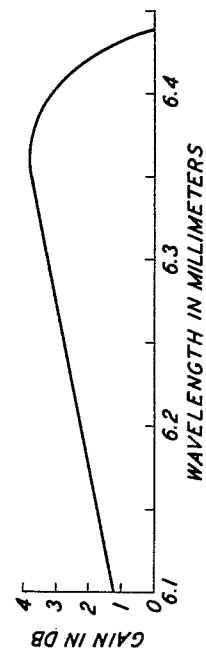
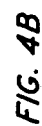


FIG. 3B



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MICROWAVE AMPLIFIER ELECTRON
DISCHARGE DEVICE

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10 Claims. (Cl. 315—3.5)

This invention relates to space discharge devices and more particularly to microwave amplifying devices of the kind generally known as traveling-wave tubes.

Traveling-wave tubes utilize the interaction between a stream of charged particles and a traveling electromagnetic wave to secure gain. One type of traveling-wave tube utilizes a helix as an electric circuit along which is transmitted an electromagnetic wave supplied from an input wave source. The helical path serves to reduce the wave propagation velocity in the longitudinal direction. An electron beam source positioned before the input end of the helix projects an electron stream through the helix, parallel to its axis and in the direction of the propagation of the wave. Beyond the output end of the helix, there is positioned a collector electrode in target relation to the beam source. If the electron velocity is adjusted to be substantially the same as the wave velocity in the absence of the electron beam, the presence of and interaction with the electron beam produces amplification of the wave propagated in the direction of electron motion, which is related to the number of electrons interacting. At the output end of the helix, this amplified wave is withdrawn for utilization.

It is a broad object of this invention to improve such traveling-wave tubes for amplification at extremely short wavelengths.

Related objects are to simplify the structure and increase the gain of helix-type tubes for use at very short wavelengths, for example, microwaves of 6 millimeters.

In traveling-wave tubes of this helix type, a condition important for optimum operation is that the helix be properly aligned with respect to the electron flow. Since, at microwave frequencies, the electromagnetic field which surrounds the helix falls off sharply at increasing distances therefrom, for maximum interaction therewith, the electron flow should be as contiguous as possible to, without actual contact with, the envelope of the helix, the region of the strongest field. This requires close alignment between the electron flow and the helix envelope. However, since it is desirable for focusing simplification that the electron flow be in a straight path, it becomes important that the envelope of the helix be straight also to satisfy the above-mentioned condition for optimum operation. In most previously developed tubes of this kind, the helix is centered by the use of axially positioned spacer rods to insure the desired alignment. A tube utilizing such an arrangement, for use with microwaves in the 4000-megacycle region, is described in an article by J. R. Pierce, entitled "Traveling-Wave Tubes" published in the Proceedings of the Institute of Radio Engineers, in vol. 35, pages 108 through 111 (February, 1947). However, since for shorter wavelengths the dimensions of the tube are usually decreased in proportion to the decrease in wavelength, this expedient for insuring proper alignment of the helix offers serious structural difficulties in tubes for use at very short wavelengths, for example, microwaves of 6 millimeters.

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It is, therefore, an object of this invention to insure good and uniform alignment of the helix in such tubes in a simple and practical manner.

A serious problem in such tubes for operation at very short wavelengths, for example, at 6 millimeters, is the difficulty in securing high gain. With a helix having a diameter of the order of .036 inch, the area of the surrounding field effective for interaction is small, resulting in low gain. Therefore, it is important to utilize as much of this area as possible to secure any appreciable gain. Therefore, it is desirable to minimize interference with the full utilization of this area. However, by the presence of rods for supporting the helix, which characterizes most previously developed tubes, the area of the field surrounding the helix available for the interaction necessary for gain is minimized since the field of the outside periphery of the helix is thereby substantially reduced, and it is necessary to concentrate most of the electron stream inside the helix. Since the gain is related to the extent of the interaction, the gain will be improved by increased interaction.

Moreover, in this same connection, there is a further advantage in the elimination of axial spacer rods for maintaining the helix alignment. The use of supports for the helix introduces undesirable losses due to the presence of this dielectric in the electromagnetic field. For this reason, except where loss is to be introduced to avoid oscillations, it is important to minimize the amount of dielectric material present in the electromagnetic field.

Therefore, since insufficient gain is one of the most important factors restricting the usefulness of traveling-wave tubes for very short microwaves, an important object of this invention is to increase the gain, both by making possible a larger region for beam interaction and by minimizing undesirable dielectric losses.

Another problem encountered in such tubes for use at very short wavelengths is that of good impedance matching. For efficient operation, it is necessary to match the input and output ends of the helix to their respective wave input and wave output, which are preferably wave guides. For good broad-band operation, it is necessary, of course, to have a broad-band match. At the longer microwave wavelengths, several arrangements therefor have been found satisfactory. For example, the ends of the helix have been attached to short straight conducting stubs parallel to the axis of the tube which are made to project into the input and output wave guides parallel to the electric field. There also have been refinements on this arrangement, as for example, the use of taper at the ends of the helix before attachment to the stubs.

However, it will be evident that such expedients offer too formidable problems of construction for helices to be used in tubes for very short microwave operation, for example, a helix wound to a pitch of .0065 inch with an inner and outer diameter of .030 inch and .036 inch respectively, for use in a tube for operation at 6 millimeters wavelength.

Therefore, it is another object of this invention to simplify the matching at very short wavelengths of the helix to the wave guides in helix-type tubes.

In accordance with one feature of the present invention, a closely wound helix, which is stretched to the necessary tube length, is suspended by its ends within the tube from supporting members; the helix is kept under sufficient tension so that the sagging thereof is reduced to insignificant proportions. In this manner, good alignment of the helix with the straight electron beam can be maintained with great structural simplicity. Moreover, since such a design permits ready flow of electrons contiguous to the helix both within and without, a larger

interacting region is possible with a consequent increase of amplification. In addition, the virtual elimination of the loss introduced by the dielectric supports results in improved gain.

In accordance with another feature of the present invention, the matching sections for coupling the helix to the input and output wave guides are formed by terminating the helix in cylinders formed by brazing end turns of the helix together. This design makes possible structural simplification, important for a practical embodiment, at the expense of but little sacrifice in band width.

Still another feature is the integration of the input and output wave guides as part of the tube envelope. This eliminates the necessity for the small diameter glass or quartz tubing utilized in previous arrangements passing through holes in the wave guide and makes possible a tube envelope of rugged metal details. However, it is desirable that all the metallic materials used be non-magnetic to avoid distortion of the strong magnetic field which is used to insure that the electron flow will be parallel to the axis of the helix.

A specific embodiment selected by way of example for purposes of illustration is a helix-type traveling-wave tube designed for operation at 6 millimeters in which the helix is maintained in alignment by suspension under tension from supporting members at its ends and the matching terminations therefor are formed by brazing a selected number of end turns thereof into a cylinder.

The invention will be better understood by reference to the following more detailed description of this specific embodiment, taken in connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a perspective view of a traveling-wave tube in which is embodied the features of the invention;

Fig. 2 is a longitudinal cross-section of the tube of Fig. 1;

Figs. 3A and 3B show the front and side views of the helix assembly and end supporting members of the same tube; and

Figs. 4A and 4B are graphs illustrating the frequency response of this tube.

With particular reference to Figs. 1 and 2, which show an exemplary embodiment of the invention, the traveling-wave tube 10 is constructed primarily of a non-magnetic material, which, for increased ruggedness and to eliminate need of shielding, can be a metal (e. g. copper). To avoid distortion of the strong magnetic field necessary to collimate the electron beam, it is important that the use of magnetic materials in the tube structure be kept at a minimum. Envelope 11 comprises, as integral parts thereof, a cylindrical central section 12, an input wave guide 13, an output wave guide 14, an electron gun housing 15, and a collector electrode housing 16. The circular cross-section of the central section 12 preferably has an inner diameter of at least several wavelengths. Within this central section and coaxial therewith is suspended the helix 17 which forms the circuit path along which are transmitted electromagnetic waves. The input and output rectangular wave guides, 13 and 14, respectively, are connected to the respective ends of the central section 12, so that, for each, one pair of sides is normal and the other parallel to the axis of the central section 12. In this way the axis of the central section 12 will be parallel to the electric field in the wave guides. Communication between the input wave guide 13 and the central section 12 is made through the cylindrical orifice 18 in the input wave guide wall interior to the central section 12 and coaxial therewith. Similarly, communication between the output wave guide 14 and the central section 12 is made through the cylindrical orifice 19 in the output wave guide wall interior to the central portion 12 and coaxial therewith. Also coaxial with the helix 17 are the cylindrical orifices 21 and 22 in the input and output wave guide walls interior

to the electron gun housing 15 and the collector electrode housing 16, respectively. Thus by means of the orifices 21, 18, 19 and 22, respectively, a path for an electron stream is defined from the electron gun housing 15 to the collector electrode housing 16 by way of the input wave guide 13, the central section 12, and the output wave guide 14.

The helix 17 is terminated in the input and output matching sections 23 and 24, respectively. The helix assembly which comprises the helix 17 and the matching sections 23 and 24, is suspended between the orifices 21 and 22 by supporting members 25 and 26 attached to the matching terminations 23 and 24, respectively. The helix assembly and the supporting members 25 and 26 are described hereinbelow in greater detail with reference to Figs. 3A and 3B. The supporting members 25 and 26 are supported respectively on ledges 21A and 22A in the walls of the respective orifices 21 and 22. The resultant structure comprises a helix assembly which extends from its support 21A in the wall of the orifice 21, through the input wave guide 13, the orifice 18, the central section 12, the orifice 19 and the output wave guide 14 to its support 22A in the wall of orifice 22. The helix assembly is of such length that the stretching necessary to fit the supporting members 25 and 26 between their respective supports in the walls of the orifices 21 and 22 provides the tautness required to prevent sagging and keep the helix axis in straight alignment.

The input wave guide 13 serves as the input wave source for the tube 10. Energy supplied thereto is transferred to the matching section 23 which acts as a receiving antenna, and the wave is transmitted along the helix 17 to the matching section 24 which radiates the electromagnetic energy out into the output wave guide 14 from which it is supplied to utilization means.

As is disclosed in the above-mentioned publication by J. R. Pierce, in order to secure amplification of the wave traveling in the helix 17, it is important to provide a stream of charged particles in interacting relation therewith. An electron gun situated in the electron gun housing 15 before the input end of the helix assembly and a collector electrode positioned in target relationship with respect to the gun in the collector electrode housing 16 beyond the output end of the helix assembly are utilized as terminals for the electron beam. The gun comprises a heater compartment 31, of which the face facing the central section 12 includes a circular disk 32 whose front surface is normal to and concentric with the axis of the helix 17. This surface is activated and serves as a cathode when heated. A heating coil 33 is provided within the compartment 31 which is supplied with heating current from the potential source 40 by way of leads 41 and 42. Lead 41 is brought out from one terminal of the heating coil 33 through a glass vacuum seal. The opposite terminal of the heating coil 33 is connected to the compartment 31 from which lead 42 is brought out through a glass seal in the manner of lead 41.

At the opposite end of the tube envelope within the collector electrode housing 15, there is positioned, in target relationship with the electron gun, the collector electrode 34 which is maintained at a positive potential with respect to the cathode 32 by means of the potential supply 50 by way of lead 45 which is brought out by a glass seal in the manner of leads 41 and 42. It may be desirable to pulse this potential to minimize the power dissipated by the helix and preserve the life of the tube. This may be done by methods well known in the art. When heated, the cathode 32 emits electrons which are directed through the input wave guide 13 by way of apertures 21 and 18, down the central section 12, and through the output wave guide 14 by way of apertures 19 and 22 to the collector electrode 34. In the path between the cathode 32 and the aperture 21, there are arranged focusing and control means for directing the electron stream emitted. Along this path and normal therewith

is first disposed the field shaping electrode 35 which preferably comprises an annular disk through whose center orifice the electron beam passes. Further along in the path of the electron path is disposed the control electrode 36 which preferably also comprises an apertured disk through which the beam passes. The potential on this electrode can be varied to control the density of the electron beam. This control potential is supplied by means of the control supply 60 by way of the lead 46, through a glass seal in the manner of lead 41. Further along the electron path and normal thereto is the accelerating electrode 37 which, in this particular embodiment, also comprises a disk apertured for passage therethrough of the electron beam. The accelerating electrode 37 is maintained at a potential positive with respect to the cathode by means of the potential supply 70 by way of the lead 48 through a glass seal in the manner of lead 41. In practice, the accelerating electrode 37 is maintained at the potential of the tube envelope 11 and the helix 17, which for convenience is made the ground potential. In turn, the cathode 32 is maintained at a potential negative to ground. This accelerating electrode potential is adjusted so that the electron beam velocity is substantially the wave velocity in the absence of an electron beam. A magnetic coil, not shown, is disposed around the exterior of the tube envelope 11 and is supplied with direct current from any suitable source, for producing a longitudinal magnetic field directed along the axis of the helix 17 for collimating the electron stream into a well defined cylindrical beam whose axis is parallel to the axis of the helix 17 and which completely surrounds both the inside and outside thereof. In this manner, the free suspension of the helix is utilized to permit a larger electron stream for interacting purposes which results in increased amplification.

In order to keep the interior of the tube envelope evacuated, the wave guides 13 and 14 are sealed off with the cover glasses 51 and 52, respectively, which are made vacuum tight, and the central section 12 is provided with the exhausting tubulation 53 to enable the interior of the envelope 11 to be evacuated.

The helix assembly is shown in greater detail in Figs. 3A and 3B. It comprises the helix 17 and the two matching sections 23 and 24. The helix 17 is of fine wire wound in a coil of uniform diameter and pitch. By keeping the coil taut, as for example, by suspending and stretching it between its two ends, the need for support to keep the helix from sagging is minimized and satisfactory results are obtained by the use of only two terminal supports. Each of the matching sections 23 and 24 is a cylinder formed by brazing contiguous end turns of the helix 17 together. The number of end turns brazed together determines the length of the matching section, which length is chosen to provide the best match.

As is described above, by stretching, it is possible to secure satisfactory alignment of the helix by the use of only two terminal supports. In this preferred embodiment, the support is supplied by means of the members 25 and 26, which are used to suspend the helix assembly from the ends of the matching sections 23 and 24. Each of the supporting members 25 and 26 is formed by three radial fins 73 spaced 120 degrees apart around the corresponding matching section. The fins are first welded lightly to the matching sections to maintain the proper orientation and rigidity during the heating period of the copper brazing which follows the welding. These radial fins 73 are set on ledges 21A and 22A in the orifices 21 and 22 so that the axis of the matching sections 23 and 24 is parallel to the electric fields in the wave guides 13 and 14, respectively.

In a tube that has been constructed for amplification of microwaves of 6 millimeters, the helix originally comprised 258.5 turns of tungsten wire of .003 inch diameter wound with a pitch of .0031 inch to have an inner diameter of .030 inch. At each end, 22.5 turns were

brazed together in a cylinder to form a matching section. In position in the tube envelope with the helix assembly suspended between the supporting member 25 and 26 in the orifices 21 and 22, the unbrazed turns are stretched to a pitch of .0065 inch. The resultant length of the helix assembly is approximately 1½ inches.

In operation, wave energy is supplied from the source 13 which is received by the input matching section 23 of the helix 17 and a traveling wave is set up along the helix 17 which is propagated towards the output matching section 24. Simultaneously a stream of electrons is emitted from the cathode 32, which is moving in the direction of the propagation of the wave to the collector electrode 34. The interaction between the traveling wave and the electron beam produces gain in the wave in a manner described more fully in the above-cited publication. At the output matching section 24, this amplified wave is withdrawn by radiation into the output wave guide 14.

Figs. 4A and 4B are graphs illustrative of the frequency response of the specific embodiment described hereinabove. In Fig. 4A, against the wavelength of the input wave applied, there is plotted the loss in the cold tube, i. e. the loss in the tube before the electron beam is turned on. It will be noted that this loss is of the order of 20 decibels. In Fig. 4B there is plotted the gain of the tube under operating conditions, i. e., the electron beam is on. It is noted that a positive gain is realized in the operating region around 6 millimeters. With reference to the loss for the cold tube, this gain is of the order of 25 decibels for microwaves of the order of 6 millimeters.

It is to be understood that the above-described specific embodiment is illustrative of the principles of the invention. Other embodiments can be devised by one skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a traveling-wave tube, means defining an electron path, a helical conductor in said path for setting up electromagnetic waves, means along said path for supplying wave energy for propagation along said conductor, means along said path for withdrawing energy from said conductor, matching sections integral with said helical conductor for coupling the input end of said conductor to the supplying means and the output end to the withdrawing means, each matching section comprising a plurality of end turns of said helix mechanically held in electrical contact with one another around the entire circumference of each turn, and means at one end of the electron path for forming and projecting an electron stream along said electron path in the direction of propagation of said waves.

2. A microwave amplifying device comprising an input and an output hollow wave guide, a central chamber coupling said input and output wave guides, a wire helix for setting up electromagnetic waves in said central chamber, matching sections integral with said helix for coupling said input wave guide to the input end of said helix and said output wave guide to the output end, each matching section comprising a plurality of end turns of said helix mechanically held in electrical contact with one another around the entire circumference of each turn, and means attached to said matching sections for suspending said helix only at each end in said central chamber.

3. A microwave amplifying device comprising an input and an output hollow wave guide, a central enclosure coupling said input and output wave guides, a wire helix for setting up electromagnetic waves in said enclosure, matching sections integral with said helix for coupling said input wave guide to the input end of said helix and for coupling the output wave guide to the output end, each matching section comprising a plurality of end turns of said helix mechanically held in electrical contact with one another around the entire circumference of each turn, and means attached to said matching sections in said input

and output wave guides for stretching and supporting said helix taut in said central enclosure.

4. A microwave amplifying device comprising hollow input and output wave guides, a central chamber coupling said input and output wave guides, a wave circuit comprising a wire helix for propagating electromagnetic waves between said input and output wave guides through said central chamber, the wire helix extending at its ends into the input and output wave guides, and supporting members in said input and output wave guides for suspending said helix tautly stretched between the input and output wave guides, said supporting members comprising a plurality of radial extensions from said helix positioned around the circumference thereof.

5. A microwave amplifying device comprising input and output hollow wave guides, a central chamber coupling said input and output wave guides, a wave circuit for propagating electromagnetic waves between said input and output wave guides comprising a wire helix, matching sections for coupling the input and output wave guides to the wave circuit, each comprising a plurality of end turns of said helix mechanically held in electrical contact with one another around the entire circumference of each turn, and means attached to said matching sections for supporting said helix tautly stretched between said input and output wave guides.

6. In an electronic device, an electron source and a target electrode defining a path of electron flow, a wave circuit comprising a helix for propagating electromagnetic waves for interaction with the electron flow, input coupling means along said path comprising a hollow wave guide for supplying high frequency waves to one end of said wave circuit, output coupling means along said path comprising a hollow wave guide for abstracting amplified high frequency waves from the other end of said wave circuit, matching means at each end of the wave circuit and extending in the associated hollow wave guides comprising a plurality of end turns of said helix mechanically held in electrical contact with one another around the entire circumference of each turn, and radial fins attached to said end turns for supporting said helix only at each end in said input coupling means and output coupling means.

7. In an electronic device for utilizing the interaction between an electron stream and a traveling wave, means for forming an electron stream and a wave guiding structure along the path of the electron stream comprising a wire helically wound along most of its length to a uniform pitch which provides an axial velocity for waves propagating therethrough substantially equal to the average velocity of the stream and characterized in that at least one end of the helically wound wire has a plurality of end turns mechanically held in electrical contact with one another around the entire circumference of each turn.

8. In an electronic device for utilizing the interaction between a traveling wave and an electron stream, an electron source and target electrode defining therebetween a path for an electron stream, a wave transmission circuit along said path comprising a wire helix tautly stretched for propagating electromagnetic waves in coupling rela-

tion with the electron stream, and support means for said helix consisting of a plurality of radial extensions from said helix positioned around its circumference at each end thereof.

9. In a radio frequency amplifier, an electron source, a target defining with said source a longitudinal path of electron flow, a wave transmission circuit disposed along the path of said flow for propagating electric waves in coupling relation comprising a taut helix of uniform pitch along the main portion of its length and having input and output coupling end portions formed of a plurality of turns mechanically held in electrical contact with one another around the entire circumference of each turn, a plurality of radial extensions circumferentially disposed around said mechanically held turns, and input and output hollow wave guides each having an opposite pair of side walls apertured for passage therethrough of the electron flow, the input coupling portion of the helix being supported in the apertured side wall of the input wave guide proximate to the electron source by the radial extensions on the mechanically held turns, the output coupling portion of the helix being supported in the apertured side wall of the output wave guide proximate to the target by the radial extensions on the mechanically held turns, the remainder of the helix being freely suspended between these two support points in alignment with the path of electron flow.

10. A space discharge device for amplifying microwave frequencies comprising means defining an electron path, a helix in said electron path, supporting members only at each end of said helix comprising a plurality of radial extensions from said helix positioned around the circumference thereof, the helix being tautly stretched between said supporting members, means coupled to said helix for propagating electromagnetic waves along said helix, and means at one end of said electron path for forming and projecting an electron stream along said electron path in the direction of propagation of said waves and contiguous with said helix.

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