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M. CHODOROW

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ELECTRON DISCHARGE DEVICE

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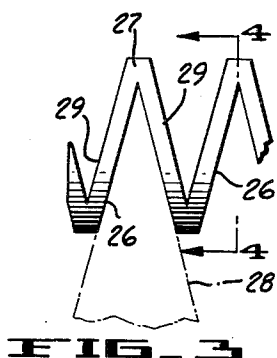
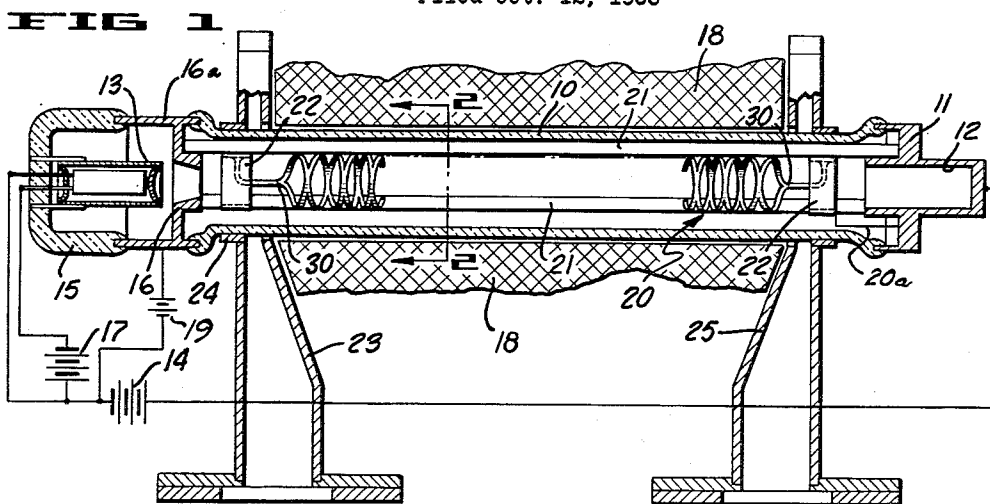


FIG. 4

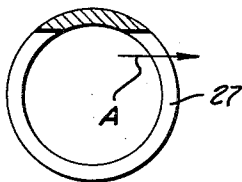


FIG. 2

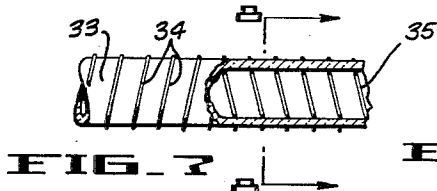
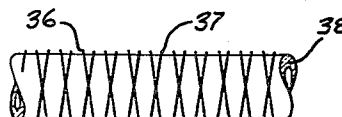
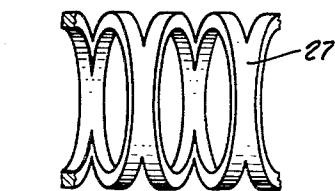
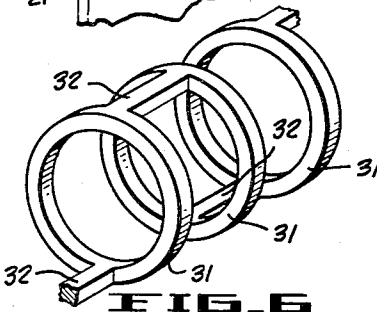
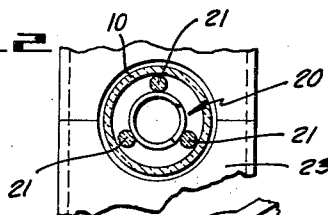
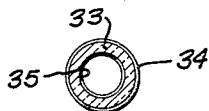


FIG. 8



INVENTOR.
MARVIN CHODOROW
BY
Paul B. Hunter
ATTORNEY

2,836,758

ELECTRON DISCHARGE DEVICE

Marvin Chodorow, Menlo Park, Calif., assignor to Varian Associates, San Carlos, Calif., a corporation of California

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7 Claims. (Cl. 315—3.6)

The present invention relates to electron discharge devices, such as traveling wave tubes wherein energy is exchanged between an electron beam and the field of a traveling radio-frequency wave, and more particularly to the structure which carries the radio-frequency wave within such devices.

In many traveling wave tubes, the radio-frequency wave is propagated on a helical structure, whose diameter and pitch are such that the longitudinal phase velocity of the wave is substantially equal to the velocity of the electron beam which is directed longitudinally of the helix. To insure optimum energy exchange or interaction between the electron beam and the radio frequency field, the operating voltage as well as the geometry of the helix must be properly chosen. It has been determined that good interaction is obtainable in practice by meeting the condition,

$$2 > \frac{2\pi a}{\lambda v/c} > 1$$

where

a = radius of the helix

λ = wavelength of the radio frequency wave

v = velocity of the electron beam

c = velocity of light

It may be noted that good interaction is still obtainable when the value of the quantity

$$\frac{2\pi a}{\lambda v/c}$$

falls below 1 but that such a low value entails the provision of a very small electron beam diameter which is impractical to achieve. Thus the stated condition, in effect, represents the practical operating range of a traveling wave tube employing a single helix as a slow-wave structure.

The foregoing condition may be met quite readily when a traveling wave tube is operated with a low voltage so that good interaction and consequently a favorable gain characteristic may be attained, but certain difficulties are encountered in tubes employing a single helix slow-wave structure when operated at relatively high voltages (10 kv. or greater).

As the voltage is raised, the beam velocity increases. Consequently, it is desirable that the radius, a , of the helix be increased a corresponding amount to enable operation in the range established by the described condition. To correlate the longitudinal phase velocity of the radio-frequency wave with the increased velocity of the electron beam, it is also necessary to increase the pitch of the helix. It has been found that such an increase in the radius and the pitch of a helix reduces its impedance and ultimately the gain characteristic of the tube. Briefly, the explanation is this: the impedance of the helix is generally expressed by the relation,

$$\frac{E^2}{\beta^2 P}$$

where

E = interaction field component or longitudinal field component of the traveling wave,

β = phase constant of the wave and,

P = total power flow.

When the helix becomes larger in radius and in pitch, the other Fourier components of the wave, which travel forwardly at different phase velocities than the interaction component, E , and do not interact with the electron beam, carry, relatively speaking, a larger amount of the total power, P , thereby subtracting from the energy in the longitudinally-directed interaction component, E , of the wave, to thus reduce the impedance value.

An additional difficulty encountered in the operation of a traveling wave tube embodying a single helix as a slow-wave structure concerns the production of oscillations by way of the so-called "backward wave." These backward wave oscillations result from the interaction of the electron beam with a Fourier component of the wave in which the energy is propagating in the opposite direction to the beam. This Fourier component has a phase velocity in the direction of the beam and substantially equal to its velocity. Such oscillations are possible in any traveling wave tube embodying a single helix as a slow wave structure and particularly if the beam almost fills the helix. These oscillations are undesired in an amplifier tube.

It is a general object of the present invention to provide a slow-wave structure for a traveling wave tube or similar electronic discharge device which will provide optimum gain characteristics for high-voltage operation.

More particularly, it is an object to provide a slow-wave structure for a traveling wave tube which will optimize the energy content of the interaction component of the traveling wave.

A further object is to provide a slow-wave structure which reduces the power in those field components of the traveling wave which do not interact with the electron beam.

Another object of the invention is to provide a slow-wave structure which substantially reduces the production of backward-wave oscillations.

These and other objects as well as the advantages arising from the present invention will be apparent from the following description of a preferred embodiment thereof as shown in the drawings wherein:

Fig. 1 is a sectional view, in part diagrammatic, of a traveling wave tube embodying the present invention,

Fig. 2 is a cross-sectional view taken along line 2—2 of Fig. 1,

Fig. 3 is a fragmentary view of the slow-wave structure shown in Fig. 1 as seen from the top thereof,

Fig. 4 is a section taken along line 4—4 of Fig. 3,

Fig. 5 is a fragmentary side view of the slow-wave structure of Fig. 1,

Fig. 6 is a perspective view of a modified form of slow-wave structure,

Fig. 7 is a side view of another modification of the slow-wave structure, part being broken away,

Fig. 8 is a section taken along line 8—8 of Fig. 7, and

Fig. 9 is a view of yet a further modified version of slow-wave structure embodying the present invention.

Generally, the present invention is embodied in a slow-wave structure which reduces the undesired Fourier components of a radio-frequency wave, the so-called ϕ -varying components, to a small value. These ϕ -varying components are those Fourier components of the wave whose amplitude vary with the angular position around the longitudinal axis of the slow wave structure. This accomplished, in effect, by winding two helices of substantially the same diameter in opposite directions and

applying the radio-frequency wave to the resulting slow-wave structure in a manner such that the ϕ -varying components are reduced and the useful beam-interaction components of the wave propagated on the two contra-wound helices become additive. Since the ϕ -varying components encountered in the use of a single helix are reduced by the described slow-wave structure, high voltage operation of a traveling wave tube will be permitted with relatively good gain characteristics and backward wave oscillations will be substantially eliminated.

The two modes on oppositely-wound helices which correspond to the ordinarily-used mode of a single helix can be of the same or of opposite polarity. The first mode, where the condition of opposite polarity exists, produces a field between the two helices of relatively great strength and an axial or longitudinal field of negligible value. The second mode, where the two helix voltages are of the same polarity, is, to the contrary, possessed of a small field between the helices, and a large longitudinal component, which is that useful for interaction with the beam. Accordingly, it can be seen that if radio-frequency energy is applied to contra-wound helices constructed in accordance with the present invention so that the proper polarity condition is fulfilled, the first mode mentioned above will in effect be eliminated and only the useful second mode will appear on the slow-wave structure. Since this second mode is that where the helix voltages are of like polarity, it is not necessary that the helices be insulated one from the other.

In Fig. 1 is shown one embodiment of the invention in a traveling wave tube which includes a cylindrical glass casing 10 closed at one end by a collector 11. The collector 11 is hermetically sealed at its periphery to the glass casing 10 and has a central bore 12 for the collection of electrons which have traversed the length of the traveling wave tube. The collector 11 is maintained at a desired positive potential with respect to the cathode 13 of the tube by a suitable direct-current voltage source indicated at 14; the cathode 13 being mounted at the other extremity of the glass casing 10 within a glass cup 15 which is joined thereto in sealed relation by the cylindrical peripheral portion 16a of a focusing ring 16. The juncture is such that the focusing ring 16 is supported so as to direct electrons emitted from the cathode 13 in substantially a small, rectilinear beam axially or longitudinally of the tube. The cathode 13 is heated by a suitable filament connected to a filament voltage source shown schematically at 17 to produce the described emission and a positive potential is applied to the focusing ring 16 from a direct-current voltage source 19. The electrons are maintained in a small beam through the tube by means of a suitable magnetic focusing coil 18.

The slow-wave structure, generally indicated by the numeral 20, is supported axially of the tube between the cathode and collector ends thereof by means of three glass rods 21 (Fig. 2) and is provided at each end with an antenna 22 which preferably takes the form of a hollow cylindrical stub. The antenna 22 at the cathode end of the tube receives radio-frequency energy from an energy translating device such as a conventional waveguide 23 which is tapered as it approaches the tube to insure proper matching with the slow-wave structure 20 and is additionally provided with a short lateral flange 24 adjacent the antenna 22 to increase the coupling therebetween. A like structural arrangement provides for coupling radio-frequency energy from the antenna 22 at the collector end of the tube into an output waveguide section 25. Positive direct-current voltage is supplied to the slow-wave structure 20 by connection to the collector 11, as indicated at 20a.

It will be apparent that the radio-frequency energy can be coupled to the respective ends of the slow-wave structure 20 by conventional coaxial lines. The center conductor of each coaxial line is connected to one end of the slow-wave structure and the outer conductor can

be connected to a metallic shield surrounding the glass casing.

The slow-wave structure 20 shown in Figs. 1, 2, 3, 4 and 5 embodies the contra-wound helices previously discussed, the structure being fabricated in a particularly simple manner. A series of V-shaped notches 26 are cut along one side of cylindrical metal tube 27 by a milling cutter, indicated in phantom at 28 in Fig. 3, and which passes through the tube as shown by the arrow A in Fig. 4. The tube is then rotated one-half turn and a second series of notches 29 staggered with respect to the first series but of the same configuration are cut from this side of the tube 27.

As shown in Fig. 1, the notches 26, 29 are enlarged adjacent the input and output ends to increase the pitch of the helices and thus establish proper matching with the input and output waveguide circuits. Additionally, to insure that the previously described requirement of like polarity of the voltages on the contra-wound helices be met, each antenna is connected to the helices at a common terminal, indicated at 30. Thus, two helical and electrically-parallel paths for radio-frequency energy flowing through the opposed elements of the helices are provided by the slow-wave structure of Fig. 1, which, as previously discussed, both reduce the power lost in the non-interacting Fourier components and substantially eliminate backward-wave oscillations.

Alternatively, other structures can be fabricated which, in effect, provide helical and electrically-parallel paths for a radio-frequency wave. As shown in Fig. 6, a slow-wave structure embodying the contra-wound helix principle is formed by a series of rings 31, each of which is joined to the rings on opposite sides thereof at points spaced 180° with short bars 32 whose length is, of course, determined by the velocity of the beam and the frequency of the radio-frequency wave. This, as well as the first described slow-wave structure are mechanically rigid so that they can be mounted in various manners within a tube depending upon space and structural limitations.

In Figs. 7 and 8 is shown a modification providing helices insulated one from the other and which includes a cylindrical glass tubular support 33 having helices 34, 35 formed of wire applied to the interior and exterior surfaces thereof. The only limitation on such a structure is that the thickness of the tubular support 33 be not too great so that the diameters of the helices 34, 35 will not be too variant. Otherwise, a certain amount of power will be carried by the ϕ -varying components and will thus be lost as useful energy.

The contra-wound helices can, of course, be formed of wires 36, 37 both of which are wound on the exterior of a glass tube 38, as shown in Fig. 9. Since, in every case, the helices are arranged so as to propagate the mode where the voltages are of like polarity, it is irrelevant, as mentioned hereinbefore, whether the helices contact as here in Fig. 9 or are insulated from one another as shown in Figs. 7 and 8.

It will be observed that each of the various described contra-wound helix structures is supported by a glass cylinder or by glass tubes. Such supports, when utilized with a single helix slow-wave structure, cause a reduction in the impedance,

$$\frac{E^2}{\beta^2 P}$$

as previously defined. However, the noted reduction of power carried by the non-interacting Fourier components of the radio-frequency wave, which results from the contra-wound helix construction, substantially reduces the losses incurred in glass or any other dielectric supporting members. Consequently, from a number of aspects, the contra-wound helix slow wave structure embodying the present invention optimizes the exchange of energy between an electron beam and the field of a traveling radio-frequency wave.

Various other modified versions of the slow-wave structure embodying the present invention are obviously possible. Additionally, the slow-wave structure, as herein described, may be employed to advantage not only in traveling wave tubes, but also in other electron discharge devices wherein an electron beam is to exchange energy with a radio frequency field; one example being the linear accelerator. In view of these alternatives and possible further modifications, I do not wish to be limited to the specific structure recited hereinabove. Rather, such structure should be considered merely as exemplary, and the intended scope of the invention is given by reference to the appended claims.

What is claimed is:

1. In an electron discharge device wherein energy is exchanged between an electron beam and the field of a radio frequency wave, apparatus for propagating the radio frequency wave comprising a contra-wound slow wave structure having but two contra-wound helices presenting two electrically parallel paths for the propagation of the wave, an energy translating device for interchanging energy with said apparatus, said slow wave structure having a common end termination interconnecting said two helices, a single antenna conductor connected to said common termination and coupled to said translating device such that the currents in said helices are in phase, equal and in parallel, whereby longitudinal field components of the wave are additive along such structure.

2. In an electron discharge device wherein energy is exchanged between an electron beam and the field of a radio frequency wave, apparatus for propagating the radio frequency wave comprising a slow wave structure provided with a single pair of contra-wound helices having helical elements connected in parallel with recurring junctions along the length thereof and presenting two electrically parallel paths for the current of the propagated wave, such currents being of the same phase and amplitude in said parallel paths, such structure having a configuration such that the undesired Fourier components of the wave are reduced to a small value, the helical elements of said pair of contra-wound helices at the end of said structure being interconnected and having a common terminal, and a single antenna for the end of said structure having a single lead connected to the common terminal of said structure for leading energy into and out of the same.

3. An electron discharge device wherein energy is exchanged between an electron beam and the field of a radio frequency wave comprising, means for setting up an electron beam, apparatus for surrounding the beam and propagating the radio frequency wave comprising a hollow slow wave structure having the effective configuration of a single pair of contra-wound helices, energy translating devices for interchanging energy with said apparatus, said slow wave structure having opposed current carrying elements with regularly recurring diametrically staggered junctions, the junctions at the ends of said structure providing terminals common to said elements, and unitary means coupling said common terminals

at each end of said structure to said translating devices such that the currents flowing in said elements are of the same amplitude and of the same phase whereby longitudinal field components of the wave are additive along such structure.

4. In an electron discharge device wherein energy is exchanged between an electron beam and the field of a radio frequency wave, apparatus for propagating the radio frequency wave comprising means for setting up an electron beam, a slotted tube-like slow wave structure for surrounding the beam and having the effective configuration of a single pair only of contra-wound helices, said structure having elements with regularly recurring common junctions, the common junctions of the end elements of said structure providing terminals at the ends of said structure common to said elements, an antenna adjacent each end of said structure, each antenna having a single lead coupled to the common terminal of said structure at a respective end thereof, whereby radio frequency voltages passing between said antenna and said common terminal provide similar polarities upon the elements of said structure and providing electrically parallel and symmetrical paths carrying similar currents for the propagation of the wave.

5. A device for propagating a radio-frequency wave according to claim 1 wherein said slow-wave structure comprises a metal tube having notches in opposite sides thereof in staggered relation.

6. A device for propagating a radio frequency wave according to claim 2 wherein said slow-wave structure comprises a pair of wires supported in contra-wound helical configuration and in electrical contact with each other at said recurring junctions.

7. In an electron discharge device wherein energy is exchanged between an electron beam and the field of a radio-frequency wave, an arrangement for propagating the radio-frequency wave comprising a slow-wave structure having the effective configuration of contra-wound helices connected in parallel at their ends so as to present electrically parallel paths along which the wave may travel whereby the undesired Fourier components of the wave are reduced to a small value, said slow wave structure comprising a pair of wires supported in contra-wound helical configuration and insulated one from the other.

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CERTIFICATION OF CORRECTION

Patent No. 2,836,758

May 27, 1958

Marvin Chodorow

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 8, beginning with "radio frequency" strike out all to and including "structure for" in line 10, and insert instead -- radio frequency wave, means for setting up an electron beam, apparatus for propagating the radio frequency wave comprising a slotted tube-like slow wave structure for --.

Signed and sealed this 20th day of June 1961.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents