July 30, 1957 A. V. HOLLENBERG 2,801,359

TRAVELING WAVE TUBE

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FIG. 1

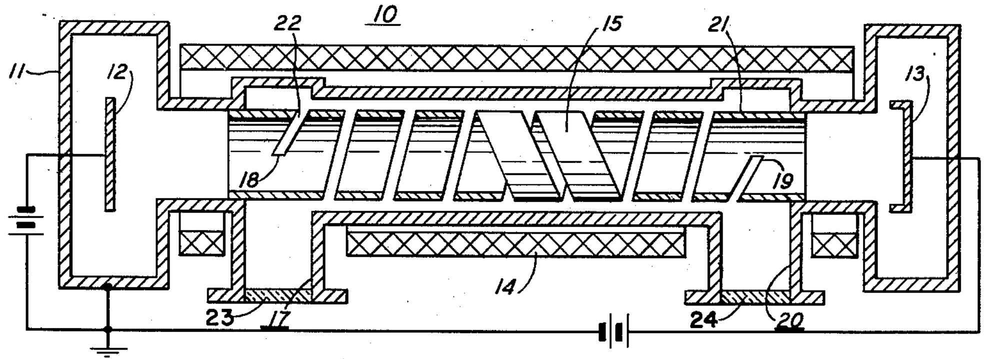
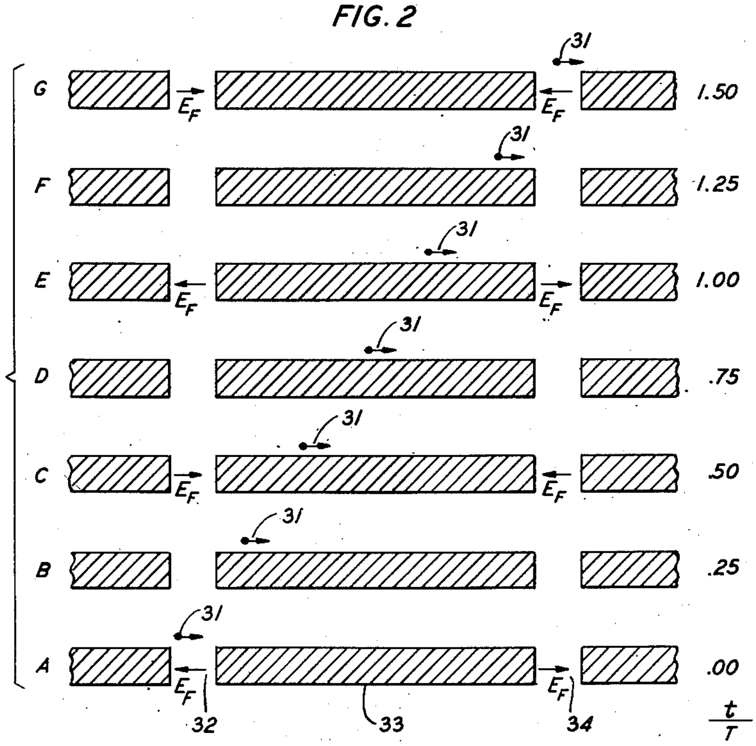


FIG. 2



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TRAVELING WAVE TUBE

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6 Claims. (Cl. 315—3.5)

This invention relates to microwave devices and more particularly to such devices which utilize the interaction between a stream of charged particles (e. g. electrons) and a traveling electromagnetic wave, such as those now generally described as traveling wave tubes.

In such traveling wave tubes, a wave transmission circuit propagates radio frequency electromagnetic waves therethrough at velocities slower than the velocity of light and an electron stream is passed in the direction of wave propagation through the electric field set up by the wave transmission circuit. By proper adjustment of the velocities of the propagated wave and the electron stream, the two can be made to interact cumulatively. In such operation, the radio frequency wave in the wave transmission circuit accelerates electrons in the beam, giving rise therein to an A.-C. velocity component which sets up an A.-C. convection current component. This latter component in turn sets up a radio frequency field of its own which combines with the radio frequency field of the wave transmission circuit. When the radio frequency wave and electron stream are properly synchronized, cumulative action and reaction between the radio frequency field of the circuit and the A.-C. current component in the stream results in a wave which grows in magnitude as it travels along the circuit and in an A.-C. current component which increases along the stream.

In such tubes, for high gain it is important to utilize a wave transmission circuit which has a high impedance to permit efficient coupling between the wave and the stream. Also, for broad band frequency operation it is desirable that the coupling be substantially uniform over the frequency range contemplated. In both these respects, the helix-type wave transmission circuit, comprising a helically wound wire conductor, is well adapted and consequently it has found wide use as an electric circuit where high gain and broad band are primary considerations. Unfortunately, the required dimensions of such helix circuits are directly related to the wavelengths in the operating range intended. For example, it has been the practice to utilize a helix in which the distance around a single turn is equal to or less than one half the operating wavelength. It has not been thought feasible to operate with larger helix dimensions since beyond this point the circuit radiation losses increase rapidly and the coupling efficiencies decrease. As a result, for operation in the short microwave region, very fine and delicate helices become necessary. Such helices are difficult both of construction and assembly and additionally have such limited power dissipative characteristics as not to lend themselves to high level power operation.

Accordingly, one object of this invention is to provide a novel and more rugged helix wave transmission circuit for use in traveling wave tubes.

Related objects are to facilitate the assembly and construction of such helix-type tubes, to increase their power

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handling capacities, and to make practical the use of larger size helices.

Another object of the invention is to provide a novel wave circuit adaptable for spatial harmonic wave operation with a circularly cylindrical electron stream.

The principal feature of the present invention is a wave transmission circuit which comprises a helically wound ribbon conductor having its broad dimension parallel to the direction of electron flow and its narrow dimension transverse to the electron flow. It has been found that such a ribbon helix, if properly dimensioned, can be operated efficiently with greater distances around turns than conventional wire helices.

It has been discovered that although the radiating losses increase as the helix circumference increases beyond the half wavelength of the operating frequency limit, these decrease again as the helix circumference approaches a three halves wavelength distance. In general, it has been found that the radiating losses can be kept low even for a large helix circumference if the distance around a single turn is adjusted to approximate an integral odd number of half wavelengths of the operating frequency. Moreover, it has also been discovered that although in general the coupling efficiency of wire helices of such large turns is low, with most of the signal wave energy being utilized in exciting higher harmonics in the electron stream, the coupling efficiency can be increased appreciably by the use of ribbon helices to limit the region of interaction between the traveling wave and the electron stream to a series of relatively short gaps of high field strength.

In a specific illustrative embodiment of the invention to be described, the ribbon helix is wound to have a distance around a complete turn of approximately three halves the free space wavelength of the operating frequency and the ribbon width is made about four fifths of the pitch distance, thereby leaving gaps between turns of approximately one fifth the pitch distance in which gaps appreciably all of the interaction occurs.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 shows a traveling wave tube wherein there is incorporated a ribbon helix circuit in accordance with the invention; and

Fig. 2 comprises a series of sketches illustrating a simple physical picture of the interaction between an electron stream and the wave traveling along the ribbon helix.

With particular reference now to the drawings, Fig. 1 shows schematically a traveling wave amplifier **10** in which there is incorporated a ribbon helix wave circuit. The various tube elements are enclosed in an evacuated tubular envelope **11** which preferably is of a non-magnetic metal, such as copper, which permits ruggedness of structure and yet avoids disturbance of the magnetic field customarily used for collimating the electron flow. Housed at one end of the envelope **11** and insulated therefrom is the electron gun **12** of conventional structure to provide an electron stream suitable for interaction with the electromagnetic field set up by the wave transmission circuit. Such an electron gun customarily includes an electron emissive cathode, a heater unit, an intensity control element, and various electrodes for collimating and accelerating the stream, all of which except the cathode have been omitted here for the sake of simplicity. At the opposite end of the envelope, there is arranged a target electrode **13** for defining with the electron gun a longitudinal path of electron flow. A solenoid **14** positioned outside the envelope **11** provides a longitudinal magnetic field to minimize transverse components of electron flow between the electron gun and the target electrode. Along this path of electron flow, there is disposed the wave transmission circuit which, in accordance with the invention, comprises the helically wound ribbon conductor **15**. It is customary to employ a hollow cylindrical electron beam whose flow is maintained parallel and contiguous to the wide dimension of the ribbon conductor.

To realize the advantages of the invention, the ribbon helix is wound to have a plural number of half wavelengths of the operating frequency around one complete turn. As set forth above, the radiation losses from the helix are minimized, i. e., the electric field is concentrated in a thin shell close to the helix where it can be utilized, rather than radiating widely, when each complete turn is approximately an odd number of half wavelengths of the operating wavelength. In the preferred embodiment being described, the distance around one complete turn is approximately three halves the operating wavelength. It can be appreciated that this permits a helix diameter which is effectively three times the diameter of the conventional wire helix wound to have a single turn of approximately one half a wavelength of the operating frequency.

The tube is operated in the manner well known for traveling wave operation. An input electromagnetic wave being propagated in the wave guide **17**, which is a path in a wave transmission system, is applied therefrom through the glass seal **23**, and by suitable transducer means to the end **18** of the ribbon helix nearest the electron gun and is thereafter propagated along the helix to the opposite end **19**. The electron gun is energized to provide an electron flow past the ribbon helix and through its surrounding electric field. To provide longitudinal acceleration to the stream, the electron gun is operated at a potential negative to those of the ribbon helix and the target electrode by suitable voltage supply sources. Customarily, these potentials are chosen to impart a velocity to the electron stream substantially the same as the longitudinal or axial wave propagation velocity so that cumulative interaction can be secured between the electron stream and the traveling wave. At the opposite end of the wave circuit, the amplified wave is derived from the end **19** of the ribbon helix by suitable transducer means and applied through the glass seal **24** to the wave guide **20** which is a continuation of the wave transmission system of which the wave guide **17** is a part.

It can be seen that if the traveling wave and electron stream are synchronized, an electron will require a time 3/2T where T is the period of the radiation to traverse one pitch distance since this is the time taken by the traveling wave to advance one complete turn. Moreover, at microwave frequencies, under the non-radiating conditions desirable, the electric field falls off sharply with distance from the conductor so that only within a thin shell at the conductor edges which extends into the gap between helix turns will the axial electric field be relatively useful in producing gain. Accordingly, it has been found that too large a gap between turns results in inefficient coupling between the stream and the wave component to be amplified because with wide gaps a considerable portion of the energy available is being utilized in amplification of harmonic components of the wave, which except for special applications is useless. To increase the coupling with the fundamental component of the traveling wave and thereby to achieve higher coupling efficiencies, it is in accordance with the invention to utilize a wide ribbon helix to narrow the gap between turns. In particular, it can be shown that for a helix wound to have a distance of three halves wavelengths around one turn, the most efficient coupling is achieved when the ratio of the ribbon width to gap width is approximately four to one, i. e., when the ribbon width is approximately 0.8 of the pitch distance. For helices

of a greater number of wavelengths around turns, it can be expected that this ratio will be still higher.

Ribbon helices of such high ribbon-to-gap ratios can be conveniently constructed by grooving a hollow metallic cylinder along a helical path. In particular, the helical ribbon conductor **15** which forms the wave circuit in the tube **10** is of this construction. A thin-walled cylinder **21** of length sufficient to extend from the the input to output wave guides **17** and **20**, respectively, is grooved from point **18** to point **19** in the helical path **22** which thereafter forms the gap between turns. By terminating the grooving in from the two ends of the cylinder **21** as shown, there remain two ungrooved end sections by which the wave circuit can be supported conveniently in the path of electron flow. For a better impedance match to the input and output wave guide, it is advantageous to taper the pitch of the grooving at each end in a manner analogous to the practice well known in the wire helix art which acts as suitable transducer means. Of course, if desired, the helix can be constructed by winding a ribbon conductor, in which case the helix can be supported in the path of electron flow by conventional means, as by spacer rods.

In Fig. 2 there is shown a series of sketches illustrating the fields acting on an electron in its traversal of one pitch distance. Suppose, as in A, an electron **31** near the ribbon conductor **33** of the helix and in one of the gaps **32** between helix turns at an instance $t=0$, where t will be the time elapsed in traveling from this starting point, when the axial electric field across the gap shown vectorially as E_F is at a maximum and in a direction to oppose the electron motion. The electron loses energy in crossing the gap **32** and is slowed down. After the crossing it travels close to the surface of the helix where the axial electric field is small because of the presence of the ribbon conductor as shown in lines B through F. During the time the electron spends close to the ribbon helix, the field at the next gap **34** the field falls to zero, completes a cycle, and then rises to a maximum in the retarding direction as the electron arrives there as shown in line G. The various relative positions of the helix along one pitch distance are shown in terms of the ratio

$$\frac{t}{T}$$

where T is the period of one radiation of the signal wave. Thus, the electron loses energy into excitation of the helix wave in every transit across the gap and is little affected by the field between gap transits.

It can be seen from the foregoing analysis that because of the discontinuous nature of the interaction typical of a ribbon helix circuit, it is well suited for use with spatial harmonic type operation of the kind described in application Serial No. 99,757, filed June 17, 1949, by S. Millman, now Patent 2,683,238, issued July 6, 1954. In such operation the relative velocities of the wave and stream are such that while an electron traverses the average distance between adjacent intervals in which the strength of the interacting component of the field is high, the wave traverses substantially the same distance plus an integral number of wavelengths. Moreover, with such a ribbon helix circuit, it is efficient to utilize a hollow electron stream of circular cross section, a factor not associated with most previously known spatial harmonic circuits. The advantages of such an electron stream are well known. Such a stream can be projected conveniently either inside or outside the ribbon helix.

It can also be seen that a ribbon helix of this type can be similarly used as a wave circuit in amplifiers which do not employ a continuous wave circuit but employ separate input and output wave circuits to induce signal modulations upstream on a path of electron flow and to abstract output waves downstream on the path of electron flow such as the various forms of space charge amplifiers. Moreover, it should be evident that a wave circuit of this kind can find application in devices, other than amplifiers, which utilize the interaction between electron streams and traveling waves.

Accordingly, it is to be understood that the specific embodiment described is merely illustrative of the general principles of the invention. Various other arrangements can be devised by one skilled in the microwave tube art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a microwave device for utilizing the interaction between an electromagnetic wave and an electron stream, an electron source and target electrode defining a path of electron flow, and a wave transmission circuit along said path for propagating an electromagnetic wave for interaction with the electron flow consisting only of a ribbon conductor formed in a helix, the wide dimension of said ribbon extending parallel to the the path of electron flow and exceeding the gap between successive turns throughout substantially the entire length of the helix, and the distance around a complete turn of the helix being approximately a plural odd integral number of half wavelengths of the electromagnetic wave propagating along said circuit.

2. In a microwave device for utilizing the interaction between an electromagnetic wave and an electron stream comprising means defining a path of electron flow, and a wave transmission circuit in the path of said flow consisting only of a helical ribbon conductor having the wide dimension of the ribbon parallel to the direction of electron flow, said wide dimension being approximately 0.8 the pitch distance throughout a major portion of the length of the helix, and the distance around a single turn of the helix being approximately equal to three halves a wavelength of the operating frequency.

3. In combination, a source of charged particles, means for directing the charged particles from said source along a predetermined path, a slow wave transmission circuit for propagating electromagnetic waves along said path for interaction with the charged particles consisting only of a ribbon conductor formed in a helix having the wide dimension of the ribbon conductor parallel to the helix axis, said wide dimension being at least 0.8 the pitch of the helix throughout a major portion of the length of the helix, and the distance around a single turn of the helix being a plural odd number of half wavelengths at the operating frequency, an external coupling connector at one end of the slow wave transmission circuit, and impedance

matching means located at one end of said transmission circuit comprising a conductive member which includes a tapered helical grooving for matching the impedance of the helical ribbon conductor to the characteristic impedance of the external coupling connector.

4. A traveling wave tube comprising an evacuated enclosing envelope, electron gun means at one end of said envelope for projecting an electron stream along an extended path in said envelope, electron collector means at the opposite end of said envelope, and means defining a transmission circuit entirely within said envelope and at all points thereof directly adjacent said path and extending substantially the entire length of said path between said gun and said collector for propagating therealong an electromagnetic wave for interaction with said electron stream, said transmission circuit comprising only a flat ribbon conductor formed in a helix extending continuously and substantially over the entire interaction region between said electron gun means and said electron collector means, the axial width of each turn of said ribbon conductor being very large in comparison to its transverse width and said axial width being substantially larger than the gaps between adjacent turns of said helix.

5. A traveling wave tube in accordance with claim 4 and further comprising input coupling means for launching an electromagnetic wave on said flat ribbon helix and output coupling means for transferring an electromagnetic wave from said flat ribbon helix, both said coupling means including portions extending through said envelope.

6. A traveling wave tube in accordance with claim 4 wherein said flat ribbon helix has a distance around each complete turn of approximately three halves of a free space wavelength at the operating frequency and the axial width of each turn of said ribbon conductor being approximately equal to 0.8 of the helix pitch throughout substantially the entire interaction region.

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