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TRAVELING WAVE AMPLIFIER

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This invention relates to microwave devices and more particularly to devices which utilize the interaction between traveling electromagnetic waves and an electron stream, such devices now being commonly termed traveling wave tubes.

This application is a continuation-in-part of my co-pending application Serial No. 168,202 filed June 15, 1950 which relates to a high efficiency traveling wave tube.

The primary object of the present invention is to improve the gain and efficiency in such traveling wave amplifiers.

Another object is to reduce the noise level in such tubes by minimizing partition and secondary emission effects.

In traveling wave amplifiers, an electric circuit propagates radio frequency electromagnetic waves therethrough at velocities slower than the velocity of light and an electron stream is projected through the electric field set up by the electric circuit and in the direction of wave propagation. By proper adjustment of the velocities of the propagated wave and the electron stream, the wave and the stream can be made to interact in a cumulative fashion whereby amplification of the wave is realized. In such devices, it is important for high gain to utilize an electric circuit which permits efficient coupling between the wave and the stream. It has been found that a helix circuit is particularly well adapted for this purpose and consequently it has found wide use as an electric circuit.

In the past, it has generally been the practice to provide a continuous helix circuit of substantially uniform dimensions along its entire length except, perhaps, for a modification in pitch at the input and output ends for matching purposes. By the use of a continuous helix, it has been sought to avoid reflection effects which might otherwise be troublesome at discontinuities in the helix. Additionally, by maintaining the helix diameter constant, there has been facilitated the problem of maintaining the electron flow in close alignment to the helix circuit whereby the number of electrons striking the helix turns is minimized. To aid in securing the desired alignment, it is generally the practice to provide a longitudinal magnetic field which together with the longitudinal accelerating field provided by the D.-C. potential on the helix acts to keep the electron flow straight. For the helix geometry most suitable for efficient interaction along the major part of the helix circuit, it is found, however, that at the input end of the helix the combined effect of the longitudinal electric and magnetic fields is still generally insufficient to keep an inordinate number of electrons from there impinging on the helix. This is especially undesirable because, in this region of low signal level, for a good signal-to-noise ratio it is particularly important to minimize noise effects which tend to degrade the input wave.

To this end, one feature of the present invention is a wave path in which an input helix circuit of larger diameter than the helix circuit which forms the main portion of the wave circuit is utilized at the input end of

the tube to impress initially signal modulations on the electron stream. In this way, partition effects can be reduced and an improved signal-to-noise ratio achieved. Considerable simplicity of structure is achieved together with conservation of tube length, in accordance with a preferred embodiment of the invention, by fitting initial turns of the smaller helix into the end turns of the larger helix and maintaining the necessary physical separation by means of dielectric spacers. Additionally, to provide an electrical match and thereby to inhibit undesirable reflection effects at these transition regions, each of the helices is here terminated by the introduction of suitable lossy material on the dielectric spacers in a way that still permits D.-C. isolation.

Further, it is a well-known characteristic of traveling wave tube operation that within ordinary operating limits the gain per unit length varies inversely with the D.-C. voltage on the circuit which is accelerating the stream. However, focusing considerations, as described above, make it generally desirable to operate the helix at the input end at a moderately high voltage to avoid partition effects. It is found however that beyond the preliminary input section it is safe to reduce the accelerating voltage for increased gain, if corresponding changes are made in the helix geometry to assure the necessary synchronism between stream and wave. Accordingly, another feature of the invention is the application of different accelerating voltages along the electron path for increased gain. Moreover, it is characteristic of the arrangement of overlapping helices described above that different accelerating potentials can conveniently be provided on the separate helices.

Another problem in the operation of traveling wave tubes is the power limitation introduced by overheating of the helix circuit at the output end where the large electromagnetic field tends to set up large radio frequency currents. In accordance with another feature of the invention, the output section of the helix wave circuit is made of larger diameter for better heat dissipation. Such an arrangement has the additional advantage that partition effects are also reduced by this expedient, which further limits overheating. This becomes particularly important because of the tendency of the wave output circuit to cause defocusing of the electron stream which enhances partition effects and heating of the helix. Moreover, it is a further characteristic that for high power efficiencies, it is important to utilize high accelerating voltages. To this end, in accordance with another feature of the invention, the output helix circuit is operated at a higher D.-C. voltage than the main section of the wave circuit. Both of these purposes are achieved in accordance with a preferred embodiment of the invention, by inserting in this transition region as in the transition region at the input end, the end turns of the smaller main helix into the initial turns of the larger output helix, matching being effected by terminating each helix.

Since it is extremely difficult to secure accurate impedance matches between the traveling wave circuit and the signal input and output circuits over the broad frequency range in which the tube operates, components of the traveling-wave tend, therefore, to be reflected from the signal output circuit back along the wave circuit to set up a backward traveling wave. Such a backward traveling wave will be amplified if there exists any electron flow in this backward direction and oscillations, resulting in tube instability, or signal degradation may be produced. Accordingly, since it is important that this backward flow be minimized, it is important to prevent secondary electron emission from setting up a backward electron flow. To this end, another feature of the present invention is a hollow enclosure-type collector electrode in target relationship with the electron source,

which is apertured for the admittance of the electron stream and within which is provided a transverse magnetic field for the prevention of the backward emission of secondary electrons.

Additional objects and features of the present invention will appear from the following more detailed description taken in connection with the accompanying drawings, in which:

Fig. 1 illustrates a traveling wave tube with three separate non-overlapping helix sections, in accordance with the invention, as it appears without signal input and output circuits, focusing means, and other customary attachments;

Fig. 2 is a transverse cross section of the tube of Fig. 1 showing the relationships of the helices, the helix support rods, and the tube envelope;

Fig. 3 is a longitudinal cross section of a traveling wave tube with three overlapping helix sections, in accordance with a preferred embodiment of the invention, complete with signal input and output circuits, focusing means, and the customary attachments; and

Fig. 4 is an enlarged view of a transition region of the tube of Fig. 3 showing the relationship of two overlapping helix sections and the spacer rods.

With reference now to the drawings, Fig. 1 shows a traveling wave tube which is enclosed by an elongated glass envelope 21. Envelope 21 includes an enlarged portion at its left end to house an electron gun assembly, but is of uniform diameter over most of the rest of its length wherein is enclosed the wave transmission circuit, which, in this tube, is shown as three separate helices, the two end ones 22 and 23 being of larger diameter than the intermediate one 24. Envelope 21 is sealed at both ends, the interior thereof being evacuated.

Fig. 2 shows a cross section of the tube of Fig. 1 illustrating a typical arrangement for supporting the helices within the tube envelope. The larger helix 22 being supported by four ceramic spaced rods 25 interposed between the envelope 21 and the helix 22. The smaller helix 24 is then supported by four other ceramic spacer rods 26 interposed between the helix 22 and the helix 24.

Fig. 3 shows, although not necessarily to scale, the structural details of a tube which represents a preferred embodiment of the invention. The electron gun supporting assembly is of a type well known in the vacuum tube art and therefore is not shown. The electron gun assembly 30 is of the kind described in the application to which reference has been made above and accordingly a complete description thereof will not be repeated here. Essentially the electron gun comprises an electron-emissive cathode 31, a heating coil 32, a beam forming electrode 33, and an accelerating anode 34 and various insulating and spacing members, together with conducting leads leading to tube base prongs for application of the operating potentials.

To the right of the accelerating anode 34 of the electron gun assembly 30, a first elongated wire helix 41 serves as the input section of the wave transmission path. This input section is used to transfer an electromagnetic wave, applied as an input thereto, to signal modulations of the electron stream provided by the electron gun and, accordingly, should extend along the path of electron flow for a distance sufficient for this purpose. Helix 41 is of substantially uniform diameter throughout its length although the pitch thereof at the left-hand end is preferably gradually increased for impedance matching purposes. Helix 41 (or 22) is positioned within and separated from the envelope 21 by four ceramic supporting rods 42 (or 25), equally spaced about its periphery as is shown in the cross section shown in Fig. 2, which extend for most of the length of this elongated portion of the tube.

The left-hand ends of the rods 42 are supported by a collar 43 which is in the form of a hollow conducting

cylinder. Collar 43 contains slots spaced about its right-hand end to receive the left-hand ends of rods 42, and a conducting strip 44 extends to the right to connect with the left-hand end of the helix 41. A ceramic ring 45 separates the left-hand end of collar 43 from the right-hand end of the accelerating anode 34 of the electron gun assembly. A lead not shown extends from the conducting strip 44 to a tube base prong for connection to a direct-current voltage source.

The right-hand ends of the rods 42 are supported by a collar 46 which is similar to the collar 43 at the left hand end of the tube. A conducting strip 47, identical to strip 44, extends from collar 46 to the right-hand end of another elongated wire helix 48 which serves as the output section of the wave transmission path. This output section serves to transfer signal modulations on the electron stream into electromagnetic waves and accordingly should be of sufficient length for this purpose. Helix 48 like helix 41 is of substantially uniform diameter and pitch throughout most of its length but the pitch thereof at the right-hand end preferably increases gradually for impedance matching purposes.

A ceramic ring 49 is located to the right of collar 46 and supports a collector electrode 50 whose left-hand end is in the form of a short hollow conducting cylinder and the right-hand end is in the form of a hollow conducting cone. This results in a hollow enclosure apertured at the left-hand end for admittance of the electron stream provided by the electron gun. A lead 51 containing a short coiled section to serve as a high frequency choke is attached to the right-hand end of collector 50, and extends through the right-hand end of envelope 21. A lead 51A attached to collar 46 passes through ceramic ring 49 and also extends through the right-hand end of envelope 21.

Intermediate the input and output sections of the wave circuit, the helices 41 and 48, there is another elongated wire helix 52 which serves as the major portion of the wave transmission path. Helix 52 is of substantially uniform diameter and pitch and extends between the input and output sections of the wave transmission path. In accordance with one feature of the invention, the end turns of the helix 52 are overlapped at the left and right-hand ends by end turns of helices 41 and 48, respectively, as shown in Fig. 4 which illustrates in better detail the transition region between helices 41 and 52. Helix 52 is then supported around its periphery by four spacer ceramic rods 53 which are interposed between the helix 52 and the helices 41 and 48. Fig. 2 shows, for example, a typical relationship of the various spacer rods and helices within the tube envelope. The left and right-hand ends of rods 53 are, for example, supported by the collars 43 and 46 respectively, which are slotted accordingly as for the support of rods 42. Alternatively, the rods 53 can be terminated shortly beyond the ends of helix 52 and supported there by appropriate means. A lead 54 extends from the left-hand end of the helix 52 through the side wall of the tube envelope. Alternatively, the left-hand end of the helix 52 can be connected to a lead which extends along one of the spacer rods 53 and eventually through to the tube base.

To secure an electrical match at the transition portions of the wave transmission path so as to avoid reflections, the right-hand end of helix 41, the left-hand end of helix 48, and the left and right-hand ends of helix 52 are each terminated. To this end, loss material, for example, colloidal graphite, is deposited on the helix supporting rods 53 in appropriate regions for terminating the various helices as required. To maintain direct current isolation between the various helices, the loss material is distributed in separate longitudinal strips along the outside and inside of rods 53, as is shown in Fig. 4, the outer strips 55 for shorting the respective turns of the helices 41 and 48 for terminating purposes, and inner strips 56 for shorting the turns of the helix 52. In practice, it is

usually necessary to short more turns, than are shown shorted in Fig. 4.

It is a further advantage of this arrangement that the two terminations can be made to extend over the same interval of tube length whereby there is effected a saving in tube length.

The radio frequency signal wave which is to be amplified is applied to helix 41 through an input wave guide 57. Wave guide 57 is a conventional hollow rectangular wave guide which is closed at one end. Envelope 21 extends through apertures in the side walls of wave guide 57 with its axis normal to the broad surfaces of the guide. The right-hand end of collar 43 is substantially flush with the inside surface of the left-hand wall of wave guide 57 and conducting strip 44 extends about half-way into the guide midway between the narrow side walls of the guide, and is located substantially one-fifth of a signal wavelength from the closed end.

The amplified signal is withdrawn from the helix 48 through an output wave guide 58 which is substantially the same as input wave guide 57. The inside surface of the right-hand wall of the guide 58 is substantially flush with the left-hand end of collar 46. Conducting strip 47 extends half-way into the guide substantially one-fifth of a wave-length from its closed end.

In addition to the various operating potentials necessary for operation of the electron gun provided by direct current sources 59 and 60, different accelerating potentials are provided on the various helices by means of the direct-current source 60 in accordance with another feature of the invention. The most negative point of source 60 is connected to the tube base prong which connects to cathode 31. A more positive point is connected to the intermediate helix 52 by way of lead 54 while a still more positive point is connected to the helix 41 by way of the appropriate tube base prong (not shown). The most positive point is connected to lead 51A to determine the potential of helix 48. It is, of course, important that the accelerating potentials and the geometry of the various helices be chosen so that along the principal portion of each helix the axial velocity of the electromagnetic wave and the longitudinal velocity of the electron stream therethrough are sufficiently similar to permit interaction between the traveling wave and the electron stream.

In operation, the electron gun projects an electron beam lengthwise down the axis of the envelope 21 along the interior of the various helices. At the right-hand end of the tube, the electrons are caught by the collector electrode 50. In order to confine the moving electron to the relatively narrow path provided for them, a strong longitudinal magnetic focusing field is provided. The focusing field arrangement is of the kind described in the earlier mentioned application and accordingly, a complete description will not be repeated here. Essentially, this arrangement comprises a solenoid 61, which surrounds the portion of the envelope 21 between wave guides 57 and 58, and two pairs of permanent magnets 62 and 63, which are parallel to the axis of envelope 21 and are used to bridge across the input and output wave guides 57 and 58, respectively, to extend therethrough the magnetic focusing field set up by solenoid 61. Additionally, various steel plates are used to straighten out possible irregularities in the longitudinal focusing field and insure straight electron flow. To the right of the output wave guide 58 is located a resonator 65, which serves as a radio frequency choke to prevent the signal wave from being transmitted past. The resonant cavity 65 is, for example, of the annular re-entrant type. A soft steel end plate 67 is positioned adjacent the right-hand wall of resonator 65 and extends perpendicular to the axis of envelope. To the right of this, a pair of small permanent magnets 68 provides a magnetic field which is transverse to the axis of the envelope 21 and which extends across the collector electrode 50. The end plate

67 serves to shield, from one another, the longitudinal magnetic field which extends along most of the elongated portion of the tube and the transverse magnetic field extending across the collector electrode.

In the operation of this described traveling wave tube, an electron stream is projected, as previously discussed, from cathode 31 to collector 50. Along the elongated tube portion the stream tends to be confined to its path by the strong longitudinal magnetic focusing field set up by solenoid 61 and permanent magnets 62 and 63. The incoming signal wave supplied from wave guide 57 energizes coupling strip 44, which serves as an antenna, and is thereby transmitted to helix 41. This wave travels along this helix at a velocity approximating that of the electron stream and, accordingly, impresses signal modulations on the electron stream. In accordance with one feature of the invention, the helix 41 is of larger radius and operated at higher D.-C. potentials than the main portion of the wave circuit to minimize the impingement thereon of electrons deviating slightly from the desired straight flow. Beyond the helix 41, the signal modulated electron stream induces a signal wave in helix 52 which travels therethrough at the velocity of the electron stream and consequently renewed interaction results between the stream and wave which impresses still more pronounced signal modulations on the electron stream which, in turn, induces a signal wave in the output helix 48. This wave, in turn, interacts with the electron stream and is amplified. At the end of helix 48, the amplified wave energizes coupling strip 47, which finally excites a wave in output wave guide 58. From there the amplified wave can be applied to a suitable load circuit. In accordance with another feature of the invention, as previously discussed, the helix 48 is made of larger radius and operated at higher D.-C. potentials than the helix 52 for better dissipation properties and increased power output.

To enhance stability and avoid undesirable impedance effects (in addition to the spraying at their ends for matching purposes), the ceramic spacer rods 53 can be further sprayed along their length with lossy material, for example, in accordance with the teachings of the earlier mentioned application.

Moreover, as is discussed in that application, another factor tending to contribute to tube instability is that of secondary emission from the collector 50. Secondary electrons from collector 50 tend to return through the wave transmission path, giving gain in the reverse direction, thus causing regeneration, and in some instances, oscillations. In order to minimize the return of secondary electrons, asymmetry in the magnetic focusing field is purposely introduced near the collector 50. As mentioned there, a small piece of magnetic material such as iron placed at one side of the collector electrode 50 introduces a field disturbance normally sufficient to deflect secondary electrons enough to prevent their return through the circuit. In some instances, however, this expedient may be insufficient. For such cases the present invention provides additional means for reducing this undesirable effect. By means of the permanent magnets 68, a transverse magnetic field is set up across the collector 50 which cooperates with the hollow-enclosure type shape of the collector to minimize the return of secondary electrons.

It is to be understood that the above-described arrangements are illustrative of the principles of the invention. Numerous other arrangements can be devised by those skilled in the art without departing from the spirit and scope of the invention. For example, for tubes where power considerations are secondary to gain considerations, it may be preferred to derive the output wave directly from the helix 52, eliminating the third helix. Alternatively where noise considerations are secondary, it may be preferred to supply the input wave directly to the helix 52, eliminating the first helix. It can

be seen that in this way various combinations are possible, the choice of a particular one being dependent on the relative importance of noise, gain, and power considerations.

Additionally, it can be seen that many of these features are not limited to helix-type traveling wave tubes. For example, in filter type or corrugated wave guide type of wave transmission path, it may be desirable to provide separation sections therefor, each operated at a different accelerating potential and characterized by correspondingly different wave propagation velocities, in accordance with the principles set forth above. Additionally it may be desirable, at the input and output ends, to maintain a larger wall separation to the electron flow for minimizing partition effects as discussed above.

What is claimed is:

1. In a microwave amplifier, an electron source and a target electrode defining a path, first, second and third coaxially aligned helices along the path, the end turns of the first helix overlapping the initial turns of the second helix and the initial turns of the third helix overlapping the end turns of the second helix, dielectric spacer rods separating the end turns of the first helix from the initial turns of the second helix and the end turns of the second helix from the initial turns of the third helix, and lossy material distributed on the spacer rods for terminating the helices at the overlapping ends.

2. In a microwave amplifier, an electron source and a target electrode defining an electron beam, first, second and third coaxially aligned helices along a path, the end turns of the first helix overlapping the initial turns of the second helix and the initial turns of the third helix overlapping the end turns of the second helix, spacer rods separating the first and second and second and third helices, and lossy material distributed on said spacer rods in two opposite and distinct longitudinal strips, each for shorting the turns of a corresponding helix.

3. A traveling wave tube comprising an envelope, an electron source and a collector electrode spaced apart for defining therebetween an electron beam path, first, second, and third axially aligned helices arranged in succession within said envelope along said path for propagating electromagnetic wave energy in coupling relation with the

beam, the first and third helices being spaced apart along the beam path by the second helix and the second helix having an axial phase velocity less than that of the first and third helices and a diameter smaller than have the first and third helices, means including potential means connected to the first helix for accelerating the electron beam to a velocity substantially equal to the axial velocity characteristic of said first helix, means including potential means connected to the second helix for decelerating the electron beam to a velocity substantially equal to the axial velocity characteristic of said second helix, and means including potential means connected to the third helix for accelerating the electron beam to a velocity substantially equal to the axial velocity characteristic of said third helix.

4. A traveling wave tube in accordance with claim 3 wherein the end turns of the first helix overlap but are separated electrically from the initial turns of the second helix and the initial turns of the third helix overlap but are separated electrically from the end turns of the second helix.

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