

June 24, 1958

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2,840,752

BACKWARD WAVE TUBE

Filed Dec. 30, 1954

2 Sheets-Sheet 1

FIG. 1

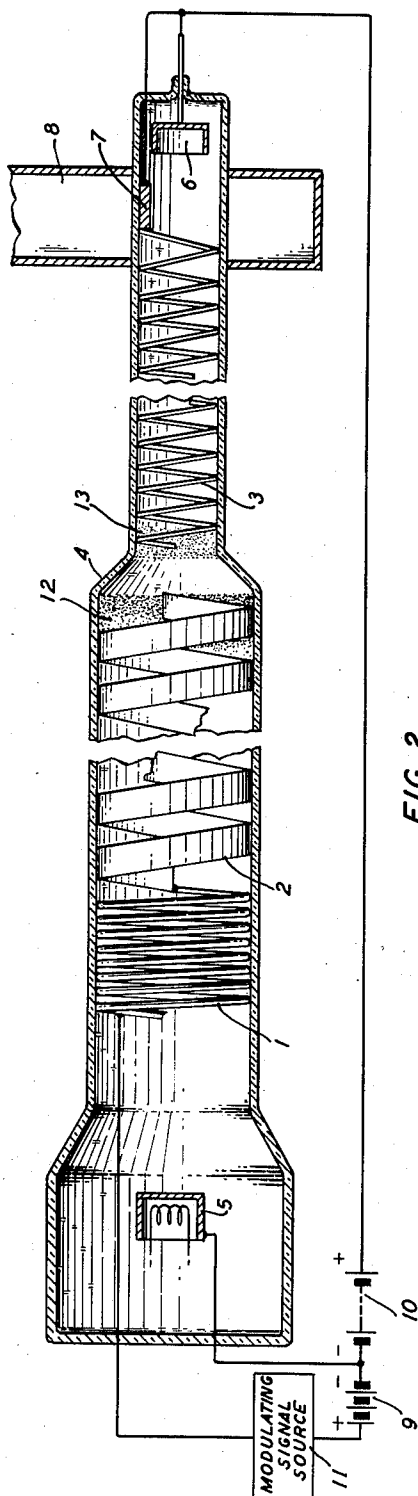
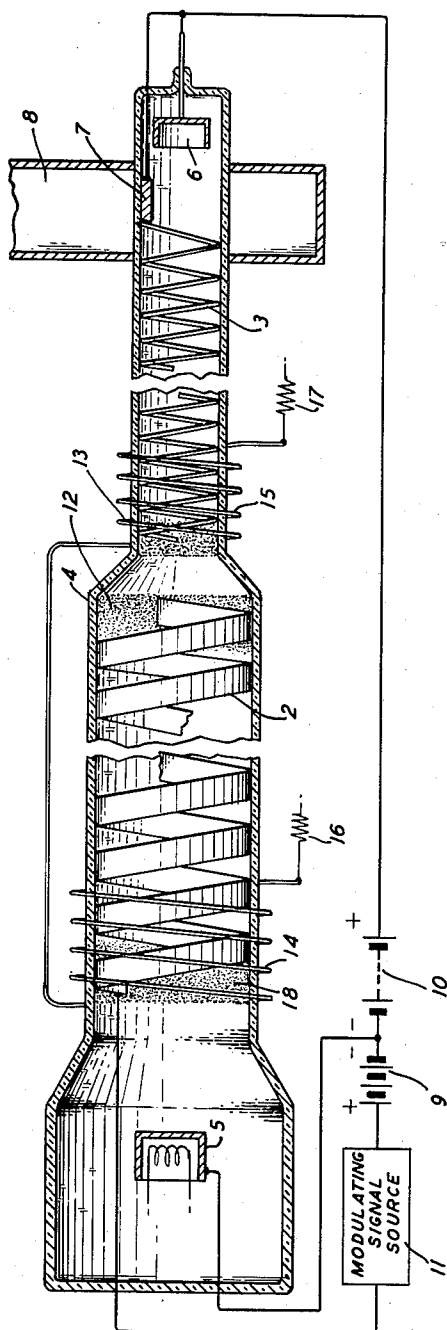


FIG. 2



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FIG. 3

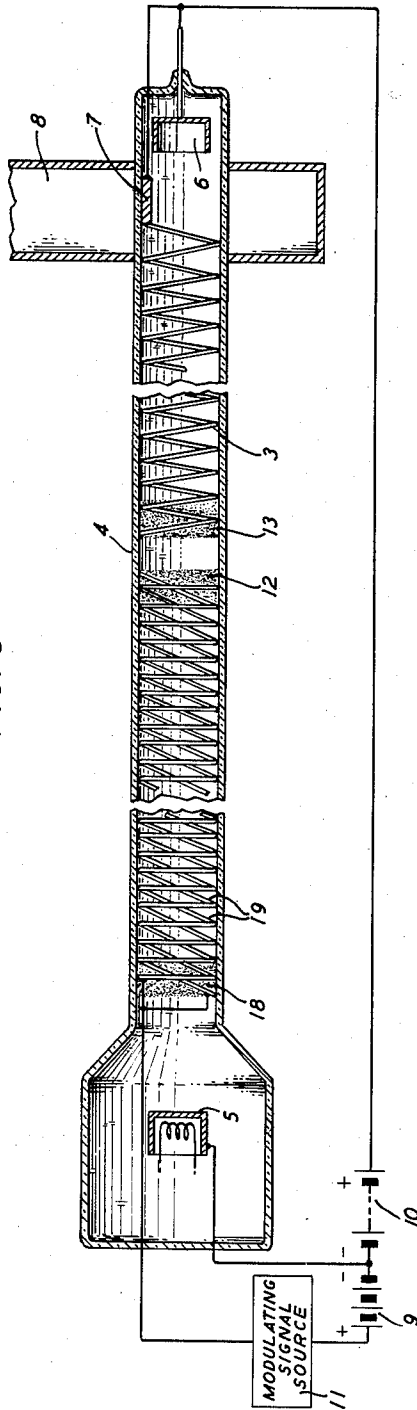


FIG. 4A

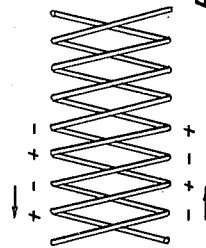


FIG. 4B

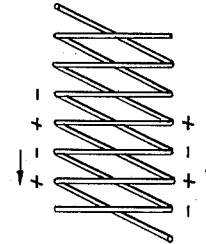


FIG. 4C

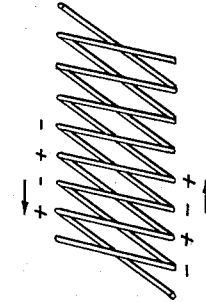
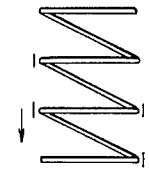


FIG. 4D



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BACKWARD WAVE TUBE

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Application December 30, 1954, Serial No. 478,686

20 Claims. (Cl. 315—3.6)

This invention relates to electronic apparatus of the kind now generally designated as traveling wave tubes which utilize the interaction between a traveling electromagnetic wave and an electron beam.

It relates particularly to the class of such tubes known as backward wave tubes and more particularly to such tubes employing helical circuits and used as oscillators.

Backward wave tubes, in general, are described in an article entitled "Backward wave tubes" by R. Kompfner and N. T. Williams, published in the Proceedings of the I. R. E., volume 41, pages 1602 through 1611, in November 1953. It may be noted in this article that such tubes utilize interaction between an electron beam and a backward traveling spatial-harmonic wave.

Backward wave tubes are also described utilizing various types of circuits in a copending application Serial No. 345,503, filed March 30, 1953, by J. R. Pierce. Since these tubes utilize the interaction between an electron beam and an oppositely directed or backward traveling wave, there is employed in them a backward wave circuit which may take any of several different forms for propagating the traveling wave. This type of circuit has the characteristic that a wave traveling with a group velocity therealong in a given direction will give rise to components which have a phase velocity in the opposite direction. The electron beam is adjusted to have a velocity substantially equal to the phase velocity of one of such components, whereby cumulative interaction between the beam and the wave component is made possible and amplification of the wave is achieved.

This type of operation is importantly applied to oscillators and it forms the basis of so-called backward wave oscillators. In the usual form of such oscillators, an electron beam is projected past a dispersive backward wave circuit which is made substantially reflectionless at the end farthest from the electron source and from which the oscillatory energy is abstracted at the end nearest to the electron source. Because the directions of wave energy propagation and of the electron flow are opposite, the electron beam provides positive feedback coupling, acting to lead energy from points of higher level to points of lower level along the path of flow and sustaining oscillations. An important advantage of such backward wave oscillators is that the frequency of the oscillations can be tuned electrically over a wide continuous band of frequencies, this property making such oscillators well suited as frequency modulators. However, full benefit of the advantageous properties of backward wave oscillators has not been had because of low efficiency and low power output. Also, the nature of efficient backward wave circuits is such that broad band coupling connections thereto are usually difficult and awkward. The problem is complicated because the impedance of the most efficient backward wave circuits normally varies widely over the oscillation band, making it difficult to keep the load well matched to the circuit continuously as is important for good coupling.

The object of this invention is to make available a

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backward wave oscillator with which the inherent potentialities of such a device may be realized through improve efficiency and power output.

To accomplish this objective, a backward wave oscillator, the circuit of which is modified in accordance with the invention as described in detail hereinafter, is utilized in combination with a separate broadband forward wave type interaction circuit. This forward wave circuit may, for example, comprise a close-pitch helix (which may be termed an output helix) to which an efficient broad band coupling connection can be made readily along the electron beam, beyond the backward wave circuit relative to the electron source. This basic arrangement of utilizing backward and forward wave circuits in combination is disclosed in a copending application of H. Heffner and R. Kompfner, Serial No. 392,946, filed November 18, 1953. In such an arrangement the electron beam, after leaving the backward wave circuit, travels along the forward wave type circuit with which it interacts to produce an amplified forward wave in that circuit. This forward wave is then abstracted at the end of the forward wave circuit farthest from the electron source. The inclusion of the forward wave circuit in this fashion serves first to provide a broad band means for converting an oscillatory space charge wave set up on the electron beam in the form of electron bunches into an electromagnetic wave. Additionally, it serves to amplify the space charge wave on the beam in the manner of a conventional traveling wave amplifier and permits the eventual abstraction of a higher level signal than could have been abstracted originally in the region immediately past the region of backward wave interaction.

Previous suggestions for using a forward wave circuit to interact with the spend electronic beam after it leaves a helical type of backward wave circuit have not been entirely successful in reaching the desired goal of obtaining substantial amplification and a greater output, and higher efficiency than with the ordinary backward wave tube. This lack of success is believed to be largely due to the fact that the spatial-harmonic fields of a helical backward wave circuit with which the electron beam interacts are not uniform around a circumference of the helix perpendicular to the axis but vary between zero and 2π so that opposite sides of the beam are oppositely poled or phased and as a result one might say the symmetrical fundamental electron "mode," characteristic of the usual forward traveling wave amplifier, is not excited.

In a forward wave circuit, like that utilized as described above, the normally used or fundamental mode being symmetrical has no variation around a circumference perpendicular to the axis so that opposite sides of the helix see in-phase fields. Because of the different symmetry involved, it can be seen that the modulation of the electron beam produced by the spatial-harmonic fields of the helix of the backward wave circuit could not properly excite the desired field in the normal close-pitch output helix of the forward wave circuit. This difficulty is overcome, according to the invention, by providing means for exciting the beam, or components thereof, in the symmetrical fundamental mode by energy generated in the backward wave circuit after which the beam wave energy is amplified, converted into electromagnetic energy, and coupled to the load circuit by means of the forward wave circuit.

The invention will be better understood from the following description and the accompanying drawings in which:

Figs. 1 and 2 show oscillator modulators in accordance with the invention which utilize a tape or ribbon wound helix as a backward wave circuit,

Fig. 3 shows an oscillator modulator in accordance

with the invention which utilizes a skewed bifilar helix as a backward wave circuit, and

Figs. 4A, 4B, and 4C are diagrams illustrating the construction and operation of the bifilar helix of Fig. 3. Fig. 4D is a diagram illustrating the construction and operation of a single helix skewed in a manner similar to the bifilar helix.

Figs. 1 and 2 employ a tape or ribbon wound helix 2 as the backward wave circuit. In the Fig. 1 embodiment of the invention, the tube envelope 4 encloses three axially aligned helices 1, 2 and 3 which are arranged in that order from the cathode 5 along the path of an electron beam projected from the cathode to collector 6. All of the helices are in coupling relation to the electron beam. A longitudinal magnetic focusing field, produced along the path of the electron beam by known means, not shown, may be employed to confine the beam laterally and maintain the desired relationship of it to the helices. The tape or ribbon wound helix 2 forms the backward wave circuit which is terminated by loss material 12 at the end farthest from the electron beam source. This loss material may be in the form of aquadag, coated on the inner surface of the envelope along the end turns of the helix or other suitably disposed energy dissipative material. The close-pitch helix 3 serves as the previously described output helix of the ordinary traveling wave type with which the electron beam, after leaving the backward wave circuit, interacts to produce amplification. The output of the tube is taken from the end of this helix farthest from the cathode by means of the conventional type coupling strip 7 which couples to the wave guide 8 leading to the load or utilization means. The helix 3 is terminated at the end nearest the cathode 5 by means of loss material 13 which may be the same as loss material 12 and it may be convenient to combine 12 and 13 into a single deposit or element.

In the usual form of backward wave oscillator, the output is taken from the end of the backward wave circuit nearest the source of the electron beam. In the arrangement of Fig. 1, according to the invention, that end of the backward wave circuit, helix 2, is terminated in a section of normal close-pitch helix 1. Helix 1, like helix 3, is of the ordinary traveling wave type usual in forward traveling wave circuits. Helix 1 is connected to be a continuation of helix 2 so that with energy derived from the backward wave circuit it excites or modulates the electron beam in the normal (symmetrical) mode (field uniform around a circumference perpendicular to the axis) which, as explained above, is the type of field required to properly energize and interact with the forward wave output helix 3. While helix 1 could be short and terminated to prevent reflection at the end nearest cathode 5 so that excitation of the beam therealong would be by the wave traveling backward in the helix only, it seems preferable to have the helix longer and unmatched at the cathode end, as shown in Fig. 1, letting the reflected wave excite the beam over a longer length. The forward wave then traveling in helix 1 continues through helix 2 and may be absorbed by loss material 12, the electron beam with the desired symmetrical modulation, derived from interaction with the forward wave in helix 1, continuing along helix 3 to the collector 6.

The circuit, as shown in Fig. 1, therefore functions as follows: an electron beam passing through the tape or ribbon helix 2 tends to accentuate a noise voltage at the frequency giving the synchronous positive feedback condition characteristic of the backward wave oscillator, i. e., a backward spatial-harmonic wave component synchronous with the electron beam velocity. This results in a wave increase toward the left on helix 2. The wave continues in the closer spaced helix 1 at a different velocity to the end nearest the cathode 5. Upon reflection, the wave reverses direction, and traveling toward the collector 6 in helix 1 near synchronism with the electron beam, produces a modulation of the symmetrical type in the beam. The wave then travels through the helix 2 and is

absorbed in the loss material 12 at the end of helix 2. Emerging from helix 2 and the region of loss material 12 and 13, the beam finds itself again in a normal traveling wave tube helix 3, accelerated to a higher potential, and near synchronous velocity with the normal wave velocity thereon. The unsymmetrical modulation of the electron beam, due to the backward wave helix 2, gives no net coupling to the helix 3 and is of little consequence. The symmetrical modulation due to helix 1, however, does couple to helix 3 and starts an increasing wave which is amplified efficiently and gives an output at the end of helix 3 nearest the collector.

To get maximum benefit of this arrangement, the tape helix 2 would normally be two or three times as large in diameter as the output helix 3 because this gives the best impedance conditions for both circuits. Consequently, a tapered magnetic focusing field, increasing in field strength from left to right in the transition region should be used. This will cause the beam, filling helix 2, to shrink to the diameter of the output helix 3.

Elevating the voltage of the output helix 3, over that of the tape or ribbon helix 2 by making the voltage of potential source 10 higher than the voltage of source 9, has the advantage of reducing the percentage of unsymmetrical velocity modulation left on the beam by the backward wave interaction in helix 2 which would tend to degrade the output performance.

Since backward wave oscillators are well adapted to use as frequency modulators and the transmission of frequency modulated signals, the modulating signal source 11 is shown connected between potential source 9 and the helix 1 as a means for varying the beam accelerating voltage for the purpose of generating such frequency modulation signals.

An alternative arrangement is to use a coupled helix to take energy from helix 1, which could then be terminated at the cathode end, and connect that coupled helix to another one introducing a wave onto helix 3. In this way a shorter section of output helix 3 would suffice to give a high efficiency output according to experience with efficiency performance in traveling wave tubes.

A modification of this alternative arrangement which is practically the equivalent, since the first mentioned coupled helix (coupling to helix 1) may as well couple to helix 2, is illustrated in Fig. 2. By thus coupling to helix 2, helix 2 may be terminated at both ends and helix 1 eliminated.

Fig. 2 differs from Fig. 1 only in respects related to the difference in method of producing the symmetrical modulation of the electron beam required for the desired excitation of and interaction with the output helix 3. Where appropriate, the designations are the same as in Fig. 1.

The helices 2 and 3 serves the same purposes as in Fig. 1 and are terminated as in Fig. 1 except that the end of helix 2 nearest the cathode is terminated by loss material 18, which may be similar to loss material 12, and is coupled to the coupling helix 14. The coupling helix 14 is connected to coupling helix 15 which is coupled to the end of helix 3 nearest the cathode 5. Thus, the helices 14 and 15 function together to transfer electromagnetic energy from the output end of the backward wave circuit (helix 2) to the nearest end of the output helix 3 for the purpose of exciting helix 3 to modulate the electron beam symmetrically (after it has left the backward wave helix 2) to permit efficient amplification by interaction between the beam and the symmetrical field of Fig. 3. The resistors 16 and 17 serve to dissipate any residual energy appearing at the unconnected ends of helices 14 and 15, respectively.

The circuit of Fig. 2 functions in the same manner as that of Fig. 1 to produce the wave increasing toward the left on helix 2. From that point, the operation differs from that of Fig. 1 because the desired symmetrical excitation or modulation of the electron beam is impressed

thereon after the beam leaves the backward wave circuit rather than before it enters that circuit. As mentioned above, the energy developed in the backward wave circuit (helix 2) is transferred by the coupling helices 14 and 15 to the near end of the output helix 3. There a symmetrical field (in phase on opposite sides of the helix), as is characteristic of the usual forward wave type of traveling wave tube helix, is set up which symmetrically modulates the beam and interacts with it to efficiently produce amplification in the manner of the usual traveling wave tube. The amplified output is coupled to the wave guide 8 by means of the commonly used coupling strip 7.

The larger diameter of helix 2, the modulating signal source 11, and the utility of the higher electron accelerating voltage applied to the output helix 3 have been explained in connection with Fig. 1.

Another method of exciting the desired symmetrical modulation component in the electron beam is to skew the helix of the backward wave circuit as shown in Fig. 3 so that the normal field pattern is distorted to give a symmetrical field component. Here, for purposes of illustration, a skewed bifilar helix 19 is employed as a backward wave circuit and due to the skewing of this helix, as will be explained, the desired symmetrical excitation or modulation of the beam is accomplished in the backward wave circuit. Thus, in Fig. 3, only two helices, the backward wave skewed bifilar helix 19, and the forward wave output helix 3, are required in coupling relation to the electron beam along its path between the cathode 5 and collector 6.

The skewing of the bifilar helix 19, as employed, is shown in the diagram Fig. 4B and the method and accomplishment of the skewing may be best understood by comparing the diagrams of Figs. 4A and 4C with that of Fig. 4B. Fig. 4A illustrates the usual form of bifilar helix, with uniform pitch, which has been used in backward wave tubes. The general principles of the use of such a bifilar helix as a backward wave circuit are described in detail in the previously mentioned copending application Serial No. 345,503, filed March 30, 1953, by J. R. Pierce. As used in a backward wave tube, the bifilar helix is operated as a helically coiled balanced two-conductor line in which the radio frequency potentials at any two corresponding points are equal but opposite with respect to an intermediate reference level. The length of the turns of the helix are made such that at a given instant there exists between contiguous turns, a radio frequency longitudinal electric field the direction of which reverses with the successive gaps between contiguous turns. This condition is illustrated by the plus and minus designations and the arrows indicating field directions on the diagrams of Figs. 4A, 4B and 4C. It may be seen from the diagram, Fig. 4A, illustrating it, that the usual bifilar helix will have out of phase (oppositely directed) fields on opposite sides (top and bottom of the diagram) taken perpendicular to the axis of the helix. This produces an unsymmetrical excitation of the electron beam (oppositely phased on opposite sides) which, as has been pointed out, will not excite the characteristic symmetrical field in a normal close-pitch forward wave helix (such as output helix 3) required for the usual type efficient forward traveling wave amplification.

In the diagram of Figs. 4B and 4C, the helices have been skewed by shifting the top of the helix to the right with respect to the bottom. When the bifilar helix is skewed, that is, one side of the helix is shifted axially with respect to the opposite side to the extent shown in Fig. 4B so that alternate half turns are perpendicular to the axis of the helix (rather than all being inclined from perpendicular as in Fig. 4A), it may be seen that the fields at opposite sides of the helix (top and bottom in the figure) are in phase, similarly directed. This will produce components of beam excitation or modulation which are symmetrical (similarly phased on opposite

sides) and thus capable of exciting the symmetrical field in a normal close-pitch forward wave helix, such as output helix 3. If the skewing of the helix is increased to double that of Fig. 4B as shown in Fig. 4C, it can be seen from Fig. 4C that no portions of turns are perpendicular to the axis and that the fields at opposite sides of the helix (top and bottom in the figure) are oppositely directed as in Fig. 4A and not favorable for use in connection with the applicants' invention.

It may be noted that in the circuit of Fig. 3, the backward wave circuit, the skewed bifilar helix 19, may be terminated at both ends as by loss material 12 and 18 and that the diameter of that helix may be of the same order as the diameter of the output helix 3. Except for the modification due to the facts that the backward wave circuit is in the form of a skewed bifilar helix and that due to the skewing of that helix the symmetrical modulation desired in the beam for use after it has left the backward wave circuit is produced in the backward wave circuit itself (thus eliminating the necessity for coils 1, 14, and 15 of Figs. 1 and 2), the operation of the circuit of Fig. 3 is the same as that of the circuits of Figs. 1 and 2.

The drawings, by means of Figs. 3, 4A, 4B and 4C, and the above description illustrate and describe the skewing of the helix of a backward wave circuit and the desirable effect thereof only as applied to a bifilar helix. Fig. 4D further illustrates that similar operation and advantages are obtained by similarly skewing a single wire or tape wound backward wave helix. For instance, by skewing the backward wave tape or ribbon wound helix of Fig. 2, the desired symmetrical modulation component will be excited in the electron beam by the backward wave circuit, eliminating the necessity for helices 14 and 15.

The circuit of Fig. 3, utilizing the skewed bifilar helix, appears to be the most advantageous of the embodiments described. Since no output connection need be made to the oscillator (backward wave) helix, the principal objection to the bifilar helix as a backward wave oscillator circuit (the coupling difficulty) is overcome. The helix being terminated at both ends, the oscillator should be relatively free of pulling effects and, being a bifilar helix, it can be made on a small diameter so that a constant beam size can be used through the entire length of the tube.

The specific embodiments which have been described and illustrated are merely illustrative of the principles of the invention and various modifications may be devised by one skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In an electronic device comprising an electron source and a collector electrode defining a path of flow for an electron beam, the combination comprising a backward wave circuit positioned along the path of flow, a forward wave circuit positioned along the path of flow between said backward wave circuit and the collector electrode, coupling means associated with said backward wave circuit to utilize energy therefrom for exciting components of the electron beam to produce fields modulated in the normal symmetrical mode of said forward wave circuit, whereby the beam may interact efficiently with the forward wave circuit to produce amplification, and means for abstracting amplified wave energy from the forward wave circuit in the region nearest said collector.

2. In an oscillator, an electron source and a collector electrode defining a longitudinal path of flow for an electron beam, a backward wave circuit located along the path of flow for propagating therealong an electromagnetic wave traveling in the direction opposite to that of electron flow, a forward wave circuit located along the path of flow between said backward wave circuit and

the collector electrode for propagating an electromagnetic wave traveling in the direction of electron flow with a field modulation which is symmetrical with respect to the beam axis, coupling means associated with said backward wave circuit to utilize energy therefrom for exciting components of the electron beam in a manner to produce symmetrical field modulation whereby the beam may couple and interact efficiently with the forward wave circuit to produce amplification, and means for coupling to the forward wave circuit to abstract amplified wave energy.

3. A device according to claim 1 in which the backward wave circuit comprises a single winding helix adapted to spatial-harmonic operation, the forward wave circuit comprises a single winding close-pitch helix adapted to operation in a forward wave type of traveling wave tube, and the means associated with the backward wave circuit for exciting the electron beam comprises a single winding close-pitch helix forming an extension of the helix of the backward wave circuit in the direction of the electron source adapted to operation in a forward wave type of traveling wave tube as is the helix of the forward wave circuit.

4. A device according to claim 1 in which the backward wave circuit comprises a single winding helix adapted to spatial-harmonic operation, the forward wave circuit comprises a single winding close-pitch helix adapted to operation in a forward wave type of traveling wave tube, and the means associated with the backward wave circuit for exciting the electron beam is coupling means for transferring electromagnetic wave energy from the end of the backward wave circuit nearest the electron source to the end of the forward wave circuit nearest the electron source.

5. A device according to claim 1 in which the backward wave circuit comprises a skewed bifilar helix, the forward wave circuit comprises a single winding helix adapted to use in a forward wave type of traveling wave tube, and the means associated with the backward wave circuit for exciting the electron beam is the skewing of the bifilar helix.

6. A device according to claim 1 in which the backward wave circuit comprises a skewed bifilar helix adapted to spatial-harmonic operation, the forward wave circuit comprises a single winding helix adapted to operation in a forward wave type of traveling wave tube, and the means associated with the backward wave circuit for exciting the electron beam is a skewing of the turns of the bifilar helix such that alternate half turns are substantially perpendicular to the axis of the helix.

7. A device according to claim 3 in which the helix of the backward wave circuit is of flat wound tape.

8. A device according to claim 3 in which the helix of the backward wave circuit is wire wound.

9. A device according to claim 4 in which the helix of the backward wave circuit is of flat wound tape.

10. A device according to claim 4 in which the helix of the backward wave circuit is wire wound.

11. A device according to claim 1 in which the backward wave circuit comprises a skewed single winding helix adapted to spatial-harmonic operation, the forward wave circuit comprises a single winding close-pitch helix adapted to operation in a forward wave type of traveling wave tube, and the means associated with the backward wave circuit for exciting the electron beam is the skewing of the helix of that circuit.

12. A device according to claim 11 in which the skewed single winding helix is of flat wound tape.

13. A device according to claim 11 in which the skewed single winding helix is wire wound.

14. A device according to claim 1 including means for increasing the electron accelerating potential in the path of the electron beam in the region of the forward wave circuit above that in the region of the backward wave circuit.

15. A device according to claim 1 in which the forward wave circuit is maintained at a higher D. C. potential with respect to the electron source than is the backward wave circuit.

16. In combination, an electron source and a collector electrode for defining a path of flow for an electron beam, a backward wave interaction circuit comprising a helix skewed such that alternate half turns are substantially perpendicular to the axis of the helix, located along the path of electron flow for impressing wave modulation of the electron beam, a forward wave interaction circuit located along the path of flow in which the wave modulation of the electron beam induces forward traveling electromagnetic waves, and means for abstracting wave energy from the forward wave circuit.

17. In combination, an electron source and a collector electrode for defining a path of flow for an electron beam, a backward wave interaction circuit comprising a bifilar helix skewed such that alternate half turns are substantially perpendicular to the axis of the helix, located along the path of electron flow for impressing wave modulation of the electron beam, a forward wave interaction circuit located along the path of flow in which the wave modulation of the electron beam induces forward traveling electromagnetic waves, and means for abstracting wave energy from the forward wave circuit.

18. In an electronic device the combination of an electron source and a collector electrode for defining a path of flow for an electron beam and a bifilar helix, skewed such that alternate half turns are substantially perpendicular to the axis of the helix, located along the path of electron flow in coupling relation to the electron beam.

19. In combination, an electron source and a collector electrode for defining therebetween a path of electron flow, a first wave circuit comprising a skewed bifilar helix positioned along the path of flow adjacent to the electron source end of the path for propagating electromagnetic waves in field coupling relation with the electron flow in a direction opposite to that of the electron flow whereby modulations are impressed on the electron flow, said bifilar helix being skewed such that alternate half turns are substantially perpendicular to the axis of the helix, means at the two ends of said first wave circuit for absorbing waves traveling therealong and making said two ends substantially reflectionless, a second wave circuit positioned along the path of electron flow adjacent to the collector end, and between said first wave circuit and the collector, wherein modulations on the electron flow set up forward waves for propagation therealong in the direction of electron flow, and an output connection coupled to the collector end of said second wave circuit for abstracting said forward waves.

20. In an electronic device the combination of an electron source and a collector electrode for defining a path of flow for an electron beam and a helix, skewed such that alternate half turns are substantially perpendicular to the axis of the helix, located along the path of electron flow in coupling relation with the electron beam.

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