

Feb. 23, 1960

A. ASHKIN
TRAVELING WAVE TUBE

2,926,281

Filed May 31, 1956

2 Sheets-Sheet 1

FIG. 1

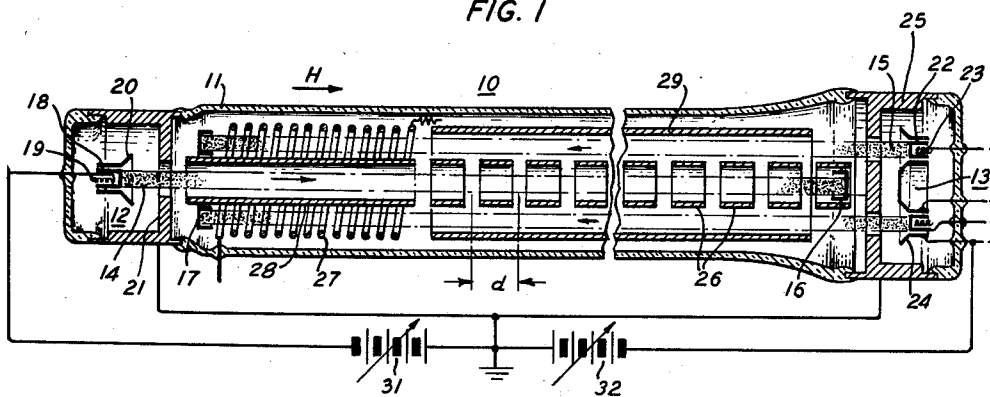
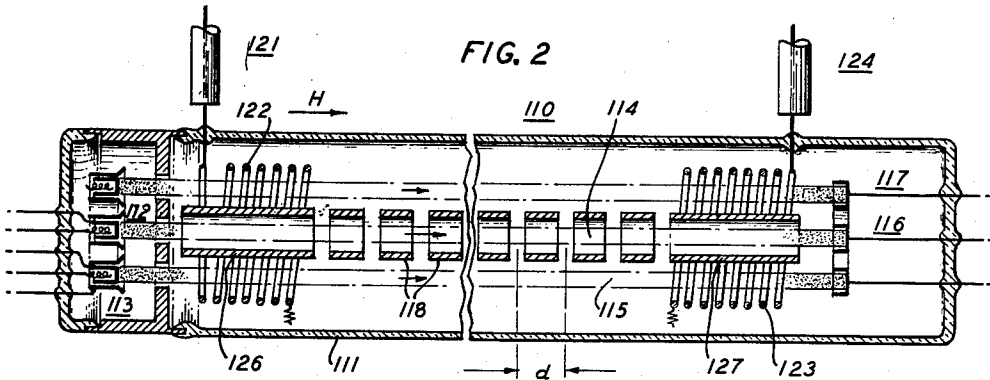


FIG. 2



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FIG. 3

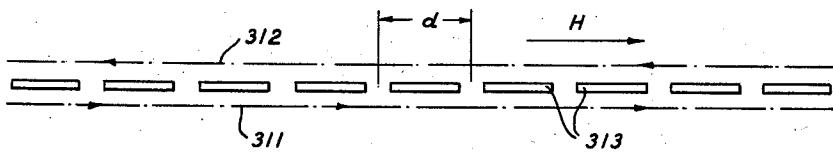


FIG. 4

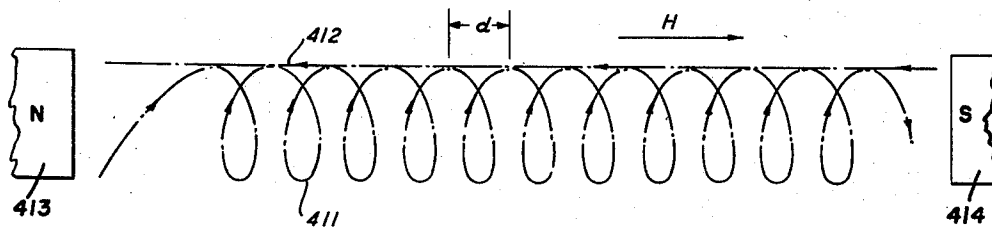
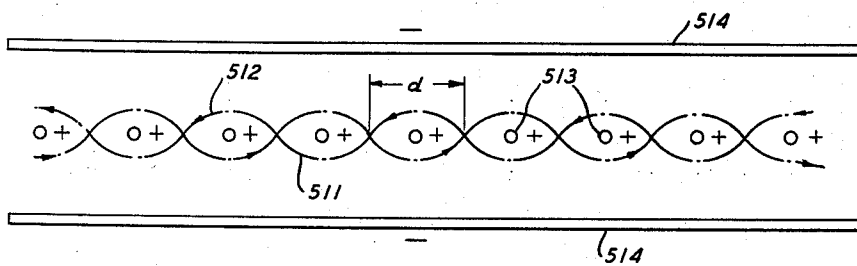


FIG. 5



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TRAVELING WAVE TUBE

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19 Claims. (Cl. 315—3.6)

This invention relates to apparatus which utilizes the phenomenon of interaction between space charge waves each of which is traveling along a separate electron beam, for achieving amplification of the waves.

In the most common form of traveling wave tube operation, an electron beam is projected along an extended path and a wave is propagated along a specially designed transmission line in close proximity to the beam. Interaction with the alternating electric field of the propagating wave causes some electrons of the beam to accelerate and others to decelerate and so periodic bunching of the beam occurs. Such bunching constitutes a space charge wave on the beam, and continued interaction between this space charge wave and the wave propagating on the circuit results in amplification of the latter.

In the present invention it is proposed to eliminate the necessity for a specially designed transmission line for propagating a wave. Such elimination is made possible since amplification in accordance with this invention is achieved, not by interaction between a propagating wave and a space charge wave on a beam, but rather, by interaction between two space charge waves each one of which is on a different electron beam. Thus the second beam in effect takes the place of a transmission line.

Interaction between two electron beams has been achieved hitherto in what have been referred to as double stream amplifiers. In these amplifiers two beams travel at different velocities along extended paths in close proximity with each other along substantially their entire lengths. By properly selecting the different velocities of the two beams, interaction occurs between the space charge waves on the two beams and amplification results. Such amplification is to be distinguished from the amplification characteristic of apparatus employing the principles wherein the two beams do not pass in coupling proximity along their entire lengths but, contrariwise, are maintained out of coupling relation with each other except at certain discrete intervals along their lengths.

Accordingly, it is a principal object of the present invention to achieve amplification by use of the interaction between two electron beams which pass in coupling proximity with each other only at discrete points along their lengths.

A related object is to achieve amplification of the so-called spatial harmonic type by use of the interaction between two electron beams.

To these ends a feature of the present invention is a traveling wave tube having means for providing two electron beams, each of which passes along an extended path, and the paths of the two beams pass in coupling proximity with one another only at certain discrete intervals spaced apart in a succession along the beam lengths. For obtaining efficient amplification the coupling intervals are equispaced along the beam lengths and the length of each is less than the length of the spacing between successive intervals.

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With coupling between two beams occurring only at equispaced discrete intervals along the beam lengths, the amplification achieved is of the so-called spatial harmonic type. The principles of this type of amplification can be found in U.S. Patent 2,683,238, issued July 6, 1954, to S. Millman. Briefly, it can be said that in the present invention amplification is achieved by appropriately selecting the velocities of the two beams and the interval between adjacent coupling points so that the phase of the space charge waves on the two beams is the same at successive coupling intervals. This does not require that the speed of the electrons of one beam travel at the same velocity as the space charge wave on the other beam, but rather that while an electron of one beam traverses the average distance between adjacent coupling intervals, the space charge wave on the other beam traverses substantially the same distance plus an integral number of wavelengths. Hence interaction is said to occur with the spatial harmonic components of the space charge wave.

In one embodiment of the present invention for use as a backward wave amplifier or backward wave oscillator, a first electron gun and target electrode are provided for projecting a first electron beam in a predetermined direction along an extended path. Additionally, a second electron gun and target are provided for projecting a second electron beam in an opposite direction along a different path which is in coupling proximity with the first path only at a plurality of discrete equispaced intervals along their lengths. When amplifier operation is desired, an input transducer is required for launching a signal wave to be amplified at the upstream end of one of the beams and an output transducer is required for extracting the amplified signal from the downstream end of one of the beams. When oscillator operation is desired, the input transducer is not required. It may be eliminated entirely or merely terminated suitably in its characteristic impedance.

In a second embodiment for use as a forward wave amplifier, the two beams are projected along different paths which likewise are in coupling proximity only at certain discrete equispaced intervals along their lengths, but they are directed in the same direction rather than in opposite directions. Input and output transducers are provided here as in the first embodiment.

The invention will be explained in greater detail in the following description taken in conjunction with the accompanying drawing, in which:

Fig. 1 is a longitudinal sectional view of a traveling wave tube which employs two oppositely directed electron beams in accordance with the present invention for forming a backward wave oscillator;

Fig. 2 is a longitudinal sectional view of a traveling wave tube which employs two similarly directed beams for forming a forward wave amplifier; and

Figs. 3 to 5 are schematic representations of alternate techniques for projecting two electron beams which pass in coupling proximity to one another only at equispaced discrete intervals.

Referring now more particularly to the various figures of the drawing, Fig. 1 shows a traveling wave tube 10 for use as a backward wave oscillator comprising an evacuated envelope 11, typically of glass or nonmagnetic metal such as copper, enclosing two electron guns 12 and 13 for forming two electron beams 14 and 15 and projecting those beams toward collectors 16 and 17, respectively. Electron gun 12 includes a cathode 18, heater 19, beam forming electrode 20, and accelerating anode 21 formed as part of envelope 11. The electron beam 14 emitted from this gun is a solid cylindrical beam having substantially circular cross section. Electron gun 13 in-

cludes an annular cathode 22, a heater 23, an annular beam forming electrode 24, and accelerating anode 25 formed as part of envelope 11. The aperture through anode 25 is annular for passing an annular beam 15 emitted by this gun. In practice, there is provided a solenoid or other magnetic means for establishing a magnetic field H whose flux lines extend along the length of the two beams for focusing them.

A succession of cylindrical shielding members 26 are positioned to surround beam 14 over a major portion of its length. These members serve to shield beam 14 from the surrounding annular beam 15 except at discrete intervals which lie between adjacent members. They thus act to restrict the points of interaction between the two beams to a succession of equispaced intervals. For most efficient interaction between the beams, the length of each of these intervals should be less than the length of one of the cylindrical members. Moreover, since interaction takes place between the two beams rather than between either or both beams and a wave propagating along the structure comprising the cylindrical members, this structure is advantageously chosen to be nonpropagating. Alternatively, if a propagating structure is used, it should be chosen to have a phase velocity nonsynchronous with both of the beam velocities to minimize coupling between the circuit and either beam.

In operation, wave manifestations existing as noise on one beam interact with those on the other beam and amplification of certain components of the noise results. This amplification occurs between a spatial harmonic component of the space charge wave on one beam and a spatial harmonic component of the space charge wave on the other beam, and so will be referred to as spatial harmonic amplification. By a proper choice of the velocities of the two beams and the average spacing d between successive intervals of interaction, such amplification can be obtained at any desired frequency. It will be helpful for a full understanding of the present invention to derive the relationship between these parameters that is necessary for amplification. Firstly, space charge waves at frequency f and wavelength λ_1 will travel along one beam at a velocity v_1 given by:

$$v_1 = f\lambda_1 \quad (1)$$

At this velocity it will take time t to travel the distance d of Fig. 1, where t is given by:

$$t = \frac{d}{v_1} \quad (2)$$

In this time, in order to achieve spatial harmonic amplification, an electron of the second beam must travel a distance $n\lambda_2 - d$, where n is any positive integer. This condition assures that the space charge waves on the two beams will have the same phase at the next interaction interval and so amplification will be achieved. Since the time for one beam to go a distance d at velocity v_1 equals the time for the other beam to go a distance $n\lambda_2 - d$ at velocity v_2 , we can equate these and obtain:

$$\frac{d}{v_1} = \frac{n\lambda_2 - d}{v_2} \quad (3)$$

Substituting

$$\lambda_2 = \frac{v_2}{f} \quad (4)$$

we obtain

$$\frac{n}{f} = d \left(\frac{1}{v_1} + \frac{1}{v_2} \right) \quad (5)$$

From this equation we observe that spatial harmonic amplification can be obtained at any frequency f by appropriately selecting the spacing d between adjacent coupling intervals and the velocities v_1 and v_2 of the two beams.

Returning now to Fig. 1, traveling wave tube 10 ex-

hibits such spatial harmonic amplification of space charge waves on both beams along the succession of conductive cylinders 26. In operation beam 14 serves in effect as a wave path for propagating a space charge wave from left to right in the tube and beam 15 as a wave path for propagating a space charge wave from right to left. Thus a closed regenerative loop is formed and oscillation occurs in this loop when the electron density of the beams is great enough to provide sufficient gain for sustaining the oscillation. At that time both beams are characterized by low level space charge waves at their upstream ends (i.e., near their respective electron guns) and, as a result of the harmonic amplification, high level space charge waves at their downstream ends (i.e., near their respective collectors). So an output signal is advantageously extracted from the downstream end of one of the beams.

In tube 10 an output signal is extracted from the downstream end of annular beam 15 by a helical conductor 27. This helical conductor must be selected to have an axial phase velocity approximately equal to the velocity of beam 15 for assuring strong coupling between the beam and the helix. Additionally, when a helical conductor is used for extracting an output signal from the beam, it is important that the space charge modulations on the beam are substantially symmetrical about the beam axis to achieve strong coupling with the helix, as the field configuration characteristic of a wave propagating along the helix is substantially symmetrical about the helix axis. Hence, with a helix as output transducer, it is important that conductive cylinders 26 are substantially pitchless. A conductive cylinder 28 is positioned within helix 27 to shield the helix from the inner beam 14 so that the space charge wave on this beam does not interfere with the signal derived from the outer annular beam. Alternatively, the helix can be arranged to extract a signal from the downstream end of the inner beam.

In practice, the various elements of the tube are maintained in place by suitable support members which have been omitted from the drawing to avoid confusion. Additionally, there are provided lead-in wires from suitable voltage sources for maintaining the various elements at appropriate D.-C. potentials. In particular, each cathode is biased to a potential slightly negative with respect to the respective beam forming electrodes and appreciably negative with respect to the accelerating anodes so that the beam will be projected toward the respective collectors which are also biased positively with respect to the cathode. To maintain the velocities of the beams constant in their flow in the region between accelerating anode 21 on the left and accelerating anode 25 on the right, these anodes and all of the tube elements in the region between them are maintained at the same D.-C. potential. However, as can be noted from Equation 5, the frequency of operation of the oscillator can be varied by varying the velocity of either or both beams. To this end variable voltage sources 31 and 32, shown schematically, are provided for varying the voltage of cathodes 18 and 22, respectively. In this manner the velocities of the two beams, although constant with length along the region of interaction, can be varied with time. In practice, however, the operating frequency of the tube of Fig. 1 will normally be varied by varying the voltage from source 31 alone, and hence only the velocity of beam 14, as the velocity of beam 15 must remain synchronous with the axial velocity of helix 27 for strong coupling thereto. Such synchronism between the beam and helix can be maintained while the velocities of both beams are varied if the variation occurs only along the succession of cylinders 26 but not along the helix 28. This condition can be achieved by energizing helix 27 and cylinder 28 with a different D.-C. potential source than that used to energize cylinders 26 and surrounding cylinder 29. With such an arrangement greater flexibility is obtained since the frequency of operation can be varied

by varying the velocity of either beam or of both beams.

Although tube 10 has been described as a backward wave oscillator, it will readily appear to one skilled in the art that it can be modified to serve as a backward wave amplifier. For use as an amplifier the beam current must be reduced to avoid undesired oscillation, and an input transducer must be provided. This transducer may be similar to the helix output transducer 27. It is, however, normally positioned at the upstream end of one of the beams for introducing at that end a signal wave to be amplified. In such a tube, as in oscillator tube 10, the output signal is extracted from the downstream end of either beam.

Fig. 2 shows a second illustrative embodiment of the present invention for use as a forward wave amplifier. This amplifier 110 differs from the backward wave amplifier just discussed in that its two beams travel in the same direction. It comprises an evacuated envelope 111 enclosing two electron guns 112 and 113, which are similar to the guns described with reference to Fig. 1, for projecting beams 114 and 115 toward collectors 116 and 117, respectively. A succession of cylindrical members 118 is positioned to surround electron beam 114 over a major portion of its length for obtaining spatial harmonic interaction between the two beams over this region. As was discussed above, the length of each of the cylindrical members is preferably greater than the spacing between successive members. Also as discussed, the velocities of these two beams and the average spacing d between successive cylindrical members 118 may be chosen to achieve amplification at any desired frequency. The relationship between these parameters for forward wave operation, derived in a manner similar to the derivation above, is the following:

$$\frac{n}{f} = d \left(\frac{1}{v_1} - \frac{1}{v_2} \right) \quad (6)$$

where n is any positive integer, d is the spacing between adjacent coupling intervals, v_1 is the velocity of the slower moving beam, and v_2 is the velocity of the faster moving beam.

In the operation of this tube, wave energy to be amplified is introduced by coaxial line 121. It passes along helical conductor 122 thereby initiating a space charge wave on the outer beam 115 which is projected at a velocity synchronous with the axial phase velocity of the helix. This wave is amplified by spatial harmonic interaction with beam 114 along the region of cylinders 118. An output signal is then extracted from the amplified space charge wave on beam 115 by helical conductor 123 whose axial phase velocity is chosen to be substantially synchronous with helix 122 and beam 115, and coupled by way of coaxial line 124 to an external circuit. Cylinders 126 and 127 are provided along the regions of helices 122 and 123, respectively, to shield the inner beam from the signal wave on the respective helices. It is to be understood that the input wave may be employed to modulate the upstream end of either beam and the output signal extracted from the downstream end of either beam.

Figs. 3 to 5 show alternative arrangements for passing two beams along paths which are in coupling proximity only at discrete equispaced intervals along the beam lengths.

In Fig. 3 two flat beams 311 and 312 are employed. These beams are projected from two electron guns shown schematically and received by two collectors. The beams are focused along their respective lengths by a magnetic field H produced by a solenoid or other magnetic means (not shown). A succession of flat conductive members 313 is positioned between the beams along the major portion of the beam lengths. Spatial harmonic interaction occurs between the beams at the various intervals between adjacent conductive members.

Fig. 4 shows an alternative technique, wherein one

beam 411 is projected at an angle ψ with the flux lines of a magnetic field H and so passes along a helical path from left to right in the figure. The magnetic field H could be established by any of the known means in the art, such as by the magnetic structure, partially illustrated schematically, comprising the pole piece members 413 and 414 positioned at opposite ends of the device. An end view of this beam would appear as a circle. Beam 412, on the other hand, passes in a straight path parallel to the flux lines of field H . This path is chosen to intersect the path of beam 411 at a succession of equispaced intervals. Spatial harmonic interaction between these two beams occurs as a result of the coupling at these intervals.

Fig. 5 shows a further technique, wherein two beams 511 and 512 are directed along the two singular equipotential surfaces characteristic of a succession of spaced conductive rods 513 positioned between a pair of parallel conductive plates 514 which are maintained at a potential negative with respect to the rods. Focusing of a beam along a singular equipotential surface in such an arrangement is often referred to as slalom focusing since the equipotential surface in side view resembles the path of a skier on a slalom. A discussion of this focusing technique can be found in United States Patent No. 2,857,548, issued October 21, 1958, of R. Kompfner and W. H. Yocom. The beams 511 and 512 in following the equipotential surfaces intersect at a spaced succession of intervals and spatial harmonic interaction occurs between the beams as a result of the coupling at these intervals.

It should be understood that the beams of each of Figs. 3 to 5 can be oppositely directed as shown, for obtaining backward wave amplification or oscillation as discussed with reference to Fig. 1, or alternatively, may be similarly directed for forward wave amplification as discussed with reference to Fig. 2. In the former case the beam velocities v_1 and v_2 and interval spacing d are chosen according to Equation 5 to obtain operation at a desired frequency, and in the latter case the values of those parameters are chosen according to Equation 6. These equations must of course be modified slightly for application to the arrangement of Fig. 4, since the distance between adjacent coupling intervals is different along the two different beam paths of that figure. It should be further understood that the various arrangements of Figs. 3 to 5 are shown as schematic illustrations. In practice these arrangements would be incorporated in tubes of the type shown in Figs. 1 and 2 with suitable input and output transducers in energy transfer relationship with the various beams as discussed with reference to those figures.

The various embodiments discussed are merely illustrative of the general principles of the present invention. In the light of this discussion, various other arrangements can be devised by one skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. A traveling wave tube comprising means for projecting a first electron beam along a predetermined extended path, means for projecting a second electron beam along a different path which is in coupling relation with the first beam only at a succession of substantially equispaced discrete intervals, the length of said discrete coupling intervals being shorter than the spacing between adjacent intervals, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

2. A traveling wave tube comprising means for projecting a first electron beam in a predetermined direction along an extended path, means for projecting a second electron beam in an opposite direction along a path which is in coupling relation with the first path only at a suc-

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sion of discrete intervals, the length of said discrete coupling intervals being shorter than the spacing between adjacent intervals, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams at its downstream end for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

3. A traveling wave tube comprising means for generating two separate electron beams and for projecting each of said beams at a different velocity along an extended path, the path of the first beam passing in coupling relation with that of the second beam only at certain substantially equispaced discrete intervals, the length of said discrete intervals being shorter than the distance between adjacent intervals, the distance between corresponding points of adjacent coupling intervals being approximately equal to

$$\frac{n}{f\left(\frac{1}{v_1} + \frac{1}{v_2}\right)}$$

where n is any integer, f is the mean frequency of operation, v_1 is the velocity of the slower moving beam and v_2 the velocity of the faster moving beam, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, an input transducer in energy coupling relation with one of said beams at its upstream end for modulating said beam in accordance with the variations in electrical strength of a signal wave to be amplified, and an output transducer in energy transfer relation with one of said beams at its downstream end for extracting therefrom the amplified signal, the other of said beams being shielded from said coupling means.

4. A traveling wave tube comprising means for generating two separate electron beams and for projecting each of said beams along an extended path, the two beams traveling in the same direction at different velocities and the path of the first beam passing in coupling relation with that of the second beam only at a succession of substantially equispaced discrete intervals, the length of said discrete intervals being shorter than the distance between adjacent intervals, the distance between corresponding points of adjacent coupling intervals being approximately

$$\frac{n}{f\left(\frac{1}{v_1} - \frac{1}{v_2}\right)}$$

where n is any integer, f is the mean frequency of operation, v_1 is the velocity of the slower moving beam and v_2 the velocity of the faster moving beam, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

5. A traveling wave tube comprising means for projecting a solid electron beam along a first extended path and for projecting an annular beam along a second extended path surrounding the path of the first beam, nonpropagating means positioned between said first and second paths for shielding said beams from one another except at a succession of substantially equispaced discrete intervals, at which intervals the beams are in coupling relation, over a distance shorter than the length of said nonpropagating means, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

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from, the other of said beams being shielded from said coupling means.

6. A traveling wave tube comprising means for projecting a first beam along an extended path, a plurality of cylinders spaced apart in a succession surrounding said first beam and forming a nonpropagating structure, the length of each of said cylinders being greater than the spacing between adjacent cylinders, means for projecting a second electron beam along an annular path surrounding said succession of cylinders and passing in energy coupling relation with the first beam only at the intervals between adjacent cylinders of said succession, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and an output transducer in energy exchange relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

7. A traveling wave tube comprising means for projecting a first beam along an extended path, a plurality of substantially pitchless conductive cylinders spaced apart in a succession surrounding said first beam and forming a nonpropagating structure, the length of each of said cylinders being greater than the spacing between adjacent cylinders, means for projecting a second electron beam along an annular path surrounding said succession of cylinders and passing in coupling relation with the first beam only at the intervals between adjacent cylinders of said succession, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and a helical conductor transmission line in energy coupling relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

8. A backward wave oscillator comprising means for projecting a first beam in a predetermined direction along an extended path, a plurality of substantially pitchless cylinders spaced apart in a succession surrounding said beam and forming a nonpropagating structure, the length of each of said cylinders being greater than the spacing between adjacent cylinders, means for projecting a second electron beam in a direction opposite to that of the first beam along an annular path surrounding said succession of cylinders, the distance between corresponding points on adjacent cylinders being approximately equal to

$$\frac{n}{f\left(\frac{1}{v_1} + \frac{1}{v_2}\right)}$$

where n is any integer, f is the mean frequency of operation, v_1 is the velocity of the first electron beam and v_2 is the velocity of the second electron beam, means for varying the frequency of oscillation comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and a helical conductor transmission line having an axial phase velocity synchronous with the velocity of one of said beams and positioned in energy transfer relation with the downstream end of said one beam for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

9. A traveling wave tube comprising means for forming two separate flat or ribbon-like electron beams and for projecting each of said beams along an extended path, the path of the first beam passing in coupling relation with that of the second beam only at a succession of substantially equispaced discrete intervals, the length of said discrete intervals being shorter than the spacing between adjacent intervals, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means

in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

10. A traveling wave tube comprising means for forming two separate flat or ribbon-like electron beams and for projecting each of said beams along an extended path, a plurality of flat conductive members spaced apart in a succession and positioned between said two beams whereby coupling between said beams is prevented except at intervals between adjacent conductive members, the length of each of said flat conductive members being greater than the spacing between adjacent members, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

11. A traveling wave tube comprising means for projecting a first flat or ribbon-like electron beam along an extended path at predetermined velocity, means for projecting a second flat or ribbon-like electron beam along a different extended path at a different velocity, means forming a nonpropagating structure including a plurality of flat conductive members spaced apart in a succession and positioned between said two beams for preventing coupling between said beams except at intervals between adjacent conductive members, the length of each of said flat conductive members being greater than the spacing between adjacent members, the distance between corresponding points of adjacent ones of said coupling intervals being approximately equal to

$$\frac{n}{f\left(\frac{1}{v_1} \pm \frac{1}{v_2}\right)}$$

where n is any integer, f is the mean frequency of operation, v_1 is the velocity of the slower moving beam and v_2 is the velocity of the faster moving beam, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

12. A traveling wave tube comprising means for generating a second electron beam and for projecting said beam along a substantially helical path, means for generating a second electron beam and for projecting said second beam along a substantially straight path which substantially intersects the helical path at one point on each of its turns, the spacing between corresponding points on adjacent turns of the helical path being of greater length than the regions in which said paths intersect, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

13. A traveling wave tube comprising means for establishing a longitudinal magnetic field, means for projecting a first electron beam at an angle with the flux lines of said magnetic field whereby said beam passes along a helical path through said magnetic field, means for projecting a second beam along a path substantially parallel to the flux lines of said magnetic field, the path of the second beam substantially intersecting that of the first beam at one point on each of the helical turns of the first path, the spacing between corresponding points on adjacent turns of said helical path being of greater length than the points of intersection on said helical

path, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

14. A traveling wave tube comprising a nonpropagating succession of rod-like conductive elements, means for maintaining said elements at a negative potential whereby there is established two substantially sinusoidal equipotential paths through said succession, means for projecting a first beam along one of said substantially sinusoidal equipotential paths, means for projecting a second beam along the second of said substantially sinusoidal equipotential paths, said equipotential paths intersecting each other at a succession of regions shorter in length than the regions separating said succession of intersecting regions, and means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, an output transducer in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

15. A traveling wave tube comprising two substantially parallel conductive plates, a plurality of rod-like conductive elements positioned between said conductive plates and spaced apart in a succession substantially parallel to said plates, whereby there are formed two substantially sinusoidal equipotential paths through said succession, said equipotential paths intersecting each other at a succession of regions shorter in length than the separation between adjacent intersecting regions, means for projecting a first beam in one direction along one of said substantially sinusoidal equipotential paths, means for projecting a second beam in an opposite direction along the second of said substantially sinusoidal equipotential paths, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and an output transducer in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

16. The combination of elements set forth in claim 15 wherein adjacent rod-like elements of the succession are spaced apart a distance approximately equal to

$$\frac{n}{f\left(\frac{1}{v_1} + \frac{1}{v_2}\right)}$$

where n is any integer, f is the mean frequency of operation, v_1 is the velocity of the first beam and v_2 is the velocity of the second beam.

17. A traveling wave tube comprising means for generating two separate electron beams, means for projecting each of said beams at a different velocity along an extended path, the path of the first beam passing in coupling relation with that of the second beam only at a succession of substantially equispaced discrete intervals, the length of said discrete intervals being shorter than the distance between adjacent intervals, the distance between corresponding points of adjacent coupling intervals being approximately equal to

$$\frac{n}{f\left(\frac{1}{v_1} \pm \frac{1}{v_2}\right)}$$

where n is any integer, f is the mean frequency of operation, v_1 is the velocity of the slower moving beam and v_2 the velocity of the faster moving beam, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other,

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and coupling means in energy transfer relation with one of said beams for extracting a signal therefrom, the other of said beams being shielded from said coupling means.

18. A traveling wave tube comprising means for projecting a first electron beam along a predetermined extended path, means for projecting a second electron beam along a different path, nonpropagating means positioned between said first and second paths for shielding said beams from one another except at a succession of substantially equispaced discrete intervals, at which intervals the beams are in coupling relation, over a distance shorter than the spacing between adjacent intervals, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

19. A traveling wave tube comprising means for projecting a first electron beam along a predetermined extended path, means for projecting a second electron beam along a different extended path which is in coupling relation with the first beam only at a succession of substantially equispaced discrete intervals, a non-

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propagating succession of members positioned between said first and second paths for shielding said beams from one another except at said succession of equispaced discrete intervals, the length of said discrete intervals being shorter than the spacing between adjacent intervals, means for varying the frequency of operation of said tube comprising variable voltage means for varying the velocity of at least one of said beams with respect to the other, and coupling means in energy transfer relation with one of said beams for extracting a signal wave therefrom, the other of said beams being shielded from said coupling means.

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