

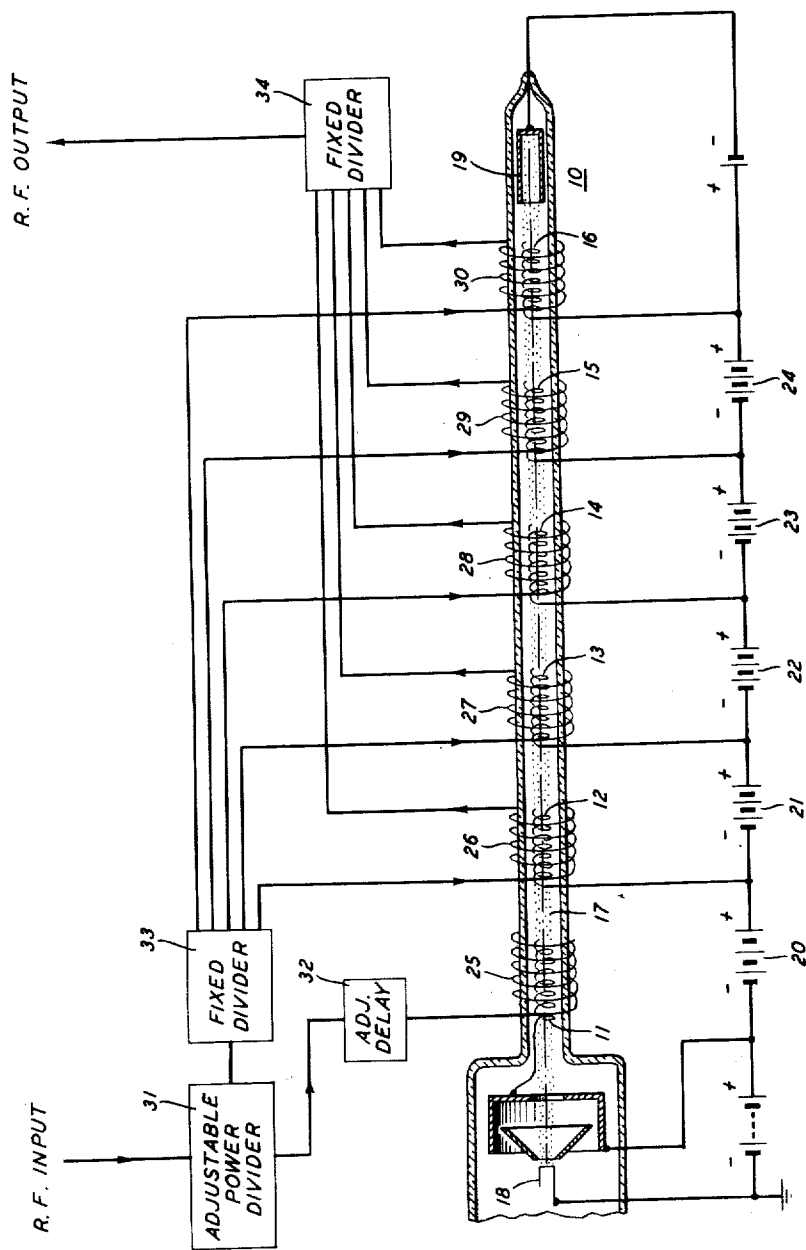
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TRAVELING WAVE TUBE AMPLIFIER

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TRAVELING WAVE TUBE AMPLIFIER

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5 Claims. (Cl. 179-171)

This invention relates to devices utilizing electron beams and more particularly to traveling wave tubes. An object of this invention is to improve the efficiency of traveling wave tubes.

Traveling wave tube amplification of wave energy makes use of the interaction which results between an electron stream and the electric field of a traveling or propagating electromagnetic wave when the electron stream is beamed in coupling relation to the wave electric field. When the electron stream is properly synchronized with the traveling wave, some of the kinetic energy of the electrons is transformed into electromagnetic energy. The electrons, as a result of this transformation, are slowed down in proportion to the energy extracted from them. As the average velocity of the electrons decreases, however, they fall more and more out of synchronism with the traveling wave until finally no useful exchange of energy is possible. To compensate for the nonuniformity in the average velocity of the electrons, it has been suggested that in a conventional helical traveling wave tube the pitch of the propagating helix be made to vary from greater to smaller down the length of the electron stream. In this manner the axial velocity of the traveling wave can be slowed down in proportion to the slowing down of the electrons. This arrangement unfortunately suffers from the disadvantages that the pitch taper for efficient operation is a function of, among other parameters, steady state beam current. Accordingly, for a given physical helix structure of this type, there is only one value of beam current and one value of radio frequency power level within a very narrow range, which can be used efficiently. Other beam currents and other power levels require different helix tapers. As a result, the versatility or flexibility of operation of this kind of tube is undesirably limited. The present invention seeks to provide a traveling wave tube which approaches, although it does not achieve, 100 percent efficiency, and which is not limited to operation with a single-valued beam current and single radio frequency power level. As will appear, one of the advantages of the invention is that the tendency of the electrons to fall out of synchronism with the traveling wave field can easily be compensated for electrically rather than in the mechanical way suggested previously and outlined above.

In accordance with the present invention, in one specific embodiment thereof, a number of slow wave circuits such as wire wound helices are positioned in succession along and surrounding the path of an electron stream. Each circuit is maintained at a higher direct potential than that of the preceding circuit so that the electrons when passing from the electrostatic field of one circuit to that of the next are accelerated by an amount corresponding to the potential difference between the two circuits. Thus the average velocity of the electrons can be maintained reasonably uniform even though a large amount of kinetic energy is being extracted from them.

A more complete understanding of the invention, to-

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gether with a better appreciation of its advantages will best be gained from a study of the following detailed description given in connection with the accompanying drawing in which the single figure shows in schematic form a traveling wave tube in accordance with the invention employing successive electron stream signal wave interaction circuits.

Referring now particularly to the drawing, the figure shows an illustrative embodiment of a traveling wave tube 10 made in accordance with the invention. In this embodiment electrons are beamed by any convenient means along an axis enclosed within an evacuated envelope of suitable dimensions. The electrons can be confined to the axis of flow by any convenient means such as a longitudinal magnetic field aligned parallel to the axis. For purposes of simplicity, however, no such means has been shown in the drawing. As the electrons travel along the axis of flow they are acted upon by successive electromagnetic fields maintained around the electron stream by appropriate means. Here these means include helices 11, 12, 13, 14, 15, and 16 which are placed around electron stream 17 at points spaced along its path from electron gun 18 to collector anode 19. These helices are maintained at potentials successively higher than the potential of cathode or gun 18. That is, helix 11 is maintained at a potential higher than that of electron gun 18 but lower than the potential of helix 12, and each succeeding helix along the length of the tube from gun 18 to collector 19 is maintained at a higher electrical potential than its preceding helix closer to gun 18. In this embodiment these potentials are supplied by sources 20, 21, 22, 23, and 24 connected to helices 11 through 16 as shown. While the voltages provided by these sources may be equal to each other it should be understood that any one of them may be adjusted to any desired value when it is convenient to do so. Surrounding each of helices 11 through 16 is a respective one of helices 25 through 30. By means of these outer helices radio frequency signals can be impressed in turn upon the inner helices and the electron stream. Helix 25 is connected to the signal input through an adjustable power divider 31 such as the directional coupler shown in United States Patent 2,532,317 to Lundstrom, which divides the input power between helix 25 and the remaining outer helices 26 through 30. The upstream ends of helices 26 through 30 are connected to the upper output line of divider 31 by means of fixed divider 33 which may, for example, be a multitap coaxial line junction. Their downstream ends are tied together at a common output terminal by means of fixed divider 34, thereby effectively connecting the helices 26 through 30 in parallel between the radio frequency signal input and output. Throughout the specification the term "upstream" is used to denote a point or location closer to the electron gun than the point or location with which it is being compared. Conversely, the term "downstream" denotes a point or location closer to the collector than the point with which it is being compared. A more specific input and output circuit is disclosed in U. S. Patent No. 2,726,291, issued December 6, 1955, of C. F. Quate.

Though not critical the length of helix 11 and of helix 25 surrounding it should be substantially one-fourth the beat wavelength, that is, the wavelength of the standing wave appearing on helix 25. The pitches of these two helices should be approximately the same in magnitude but in opposite sense. Under these conditions, wave energy applied to the left or upstream end of helix 25 will be almost entirely transferred onto helix 11 before it reaches the end of helix 25 at which point there is a node of voltage. The beat wavelength is most easily determined by measurement although it can be

determined in the way disclosed in copending application of R. Kompfner, Serial No. 355,028, filed May 14, 1953.

The lengths of helices 26 through 30 and their respective inner helices 12 through 16 should each be substantially one-half the beat wavelength. Thus both the input and output ends of the outer helices will be located at voltage antinodes and the ends of the inner helices will be located at voltage nodes.

For efficient operation of tube 10, the adjustable divider 31 is varied until the proper bunching voltage is applied to electron stream 17 via helices 25 and 11. Sources 20 through 24 may also be adjusted individually to insure that the electrons are in proper synchronism with the electric fields traveling down the various helices. The pitch of these helices, of course, determines the velocity at which these fields travel which should be approximately equal to the velocity of the electron stream.

As the electrons travel along the path of stream 17, which is congruent with the common axis of the successive helices, they first come to the region surrounded by helix 11 in which some of the electrons are retarded and others are accelerated in accordance with the variations in intensity of the signal wave propagating along the helix. By this action the electrons are bunched into groups which proceed down the tube, being timed by means of adjustable delay 32 and the gap between helices 11 and 12, to reach the region surrounded by helix 12 at the proper instant to be retarded by the signal wave propagating along the helix. The tube circuit parameters are arranged so that while within this region the electrons are decelerated by an amount corresponding to the voltage supplied by battery 20. The number of times the electrons are accelerated and decelerated in this way as they travel to the anode 19 determines the total amount of energy which can be extracted from them and consequently the amount of wave amplification obtainable.

The degree of bunching of the electron stream produced by helix 11 is a factor determining the efficiency of tube 10. As the bunching becomes more perfect the efficiency increases and this effect makes tube 10 useful as a high level expander, that is, an amplifier whose gain increases as the signal level increases.

Helices 11 through 16 provide a desirable way of impressing a bunching voltage and radio frequency signal voltages on electron stream 17 because they can be connected, without additional radio frequency insulating elements, directly to sources 20 through 24. If desired, however, these helices can be replaced by appropriate accelerating grids.

The foregoing explanation is intended in illustration and not in limitation of the principles of the invention. Various changes or modifications in the embodiment illustrated may occur to those skilled in the art and these changes may be made without departing from the spirit or scope of the invention as set forth. In particular, instead of helical wave propagating circuits such as those shown, various other wave propagating circuits may be used. Moreover, the number of circuits to be used is not limited to the number shown but may be greater or smaller depending upon the tube efficiency required. In general, the larger this number, the greater the efficiency.

What is claimed is:

1. In a device which utilizes the interaction between an electron beam and an electromagnetic wave to amplify the wave, means for forming an electron beam and for projecting the beam along a predetermined path, means located along said path for bunching said electron beam in accordance with a signal, a plurality of pairs of helices spaced downstream from said bunching means and arranged in spaced succession along the beam path for propagating electromagnetic wave energy in coupling relation with the electron beam over a distance of several wavelengths at the operating frequency, the two helices of each pair having unequal radii and being positioned

coaxially and substantially coextensively along a portion of the electron beam for forming a concentric pair having inner and outer helices, the pitch of the inner and outer helices of each of the concentric pairs being equal and of opposite sense, coupling means adjacent each concentric pair of helices in coupling relation with the outer helix of each pair, and means for maintaining at least one helix of each pair at a predetermined D.-C. potential, the predetermined potential of the helix of each pair being higher than that of the helix of the immediately preceding pair in the upstream direction along the beam path whereby electrons of the beam are accelerated as they pass from one interaction circuit to the next for maintaining the average velocity of the electron beam substantially the same at the upstream end of each successive interaction circuit along the beam path.

2. In a device which utilizes the interaction between an electron beam and an electromagnetic wave to amplify the wave, means for forming an electron beam and for projecting the beam along a predetermined path, means for bunching said electron beam, a plurality of separate interaction circuits arranged in spaced succession along the beam path for propagating electromagnetic wave energy in coupling relation with said beam, said succession extending along the beam path a distance of several wavelengths at the operating frequency and characterized in that each of the interaction circuits has substantially the same phase velocity propagating characteristics, means forming an adjustable phase delay connected between said bunching means and said interaction circuits, signal input means, an adjustable power divider coupled to said signal input means, coupling means between said power divider and each of the separate interaction circuits for introducing electromagnetic wave energy into amplifying relation with the electron beam, and means for maintaining each interaction circuit of the succession at a higher D.-C. potential than that of the circuit immediately preceding it in the upstream direction whereby electrons of the beam are accelerated as they pass from one interaction circuit to the next, the amount of this acceleration being adjusted to compensate for the decrease in velocity along the preceding interaction circuit for maintaining the average velocity of the electron beam substantially the same at the upstream end of each of the successive interaction circuits along the beam path.

3. In a device which utilizes the interaction between an electron beam and an electromagnetic wave to amplify the wave, means for forming an electron beam and for projecting the beam along a predetermined path, a plurality of separate interaction circuits arranged in spaced succession along the beam path for propagating electromagnetic wave energy in coupling relation with said electron beam, said succession extending along the beam path a distance of several wavelengths at the operating frequency, input means in coupling relation with each of said interaction circuits, output means in coupling relation with each of said interaction circuits, and each of the interaction circuits being electrically connected in parallel between the input means and the output means and being characterized in that the length of each of the parallel signal wave paths from a given point at the input means to a given point at the output means is equal.

4. In a device which utilizes the interaction between an electron beam and an electromagnetic wave to amplify the wave, means for forming and for projecting an electron beam along said path for bunching said beam in accordance with a signal to be amplified, a plurality of pairs of helices spaced downstream from said bunching means and arranged in spaced succession along said path for propagating electromagnetic wave energy in coupling and interacting relation with the beam over a distance of several wavelengths at the operating frequency, such interaction resulting in a net deceleration

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of the beam in its travel along the path, the two helices of each pair having unequal radii and being positioned coaxially with the beam and coextensively along a portion of the path of the beam, coupling means in energy transfer relation with one helix of each pair, and means for compensating for the net deceleration of said beam comprising means for maintaining at least one helix of each pair at a higher D.-C. potential than that of the helix of the immediately preceding pair in the upstream direction along said path.

5. The combination of elements as set forth in claim

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4 wherein each of the plurality of helix pairs is characterized by substantially the same phase velocity propagating characteristic.

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