

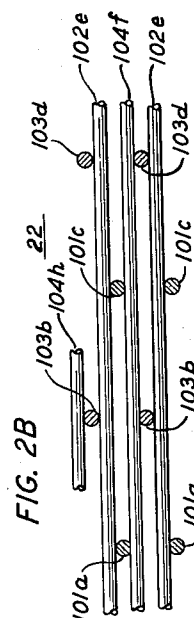
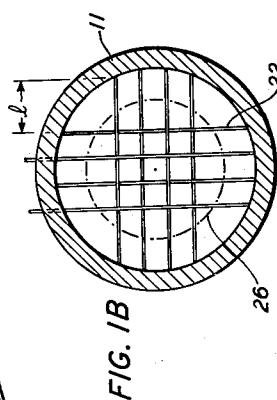
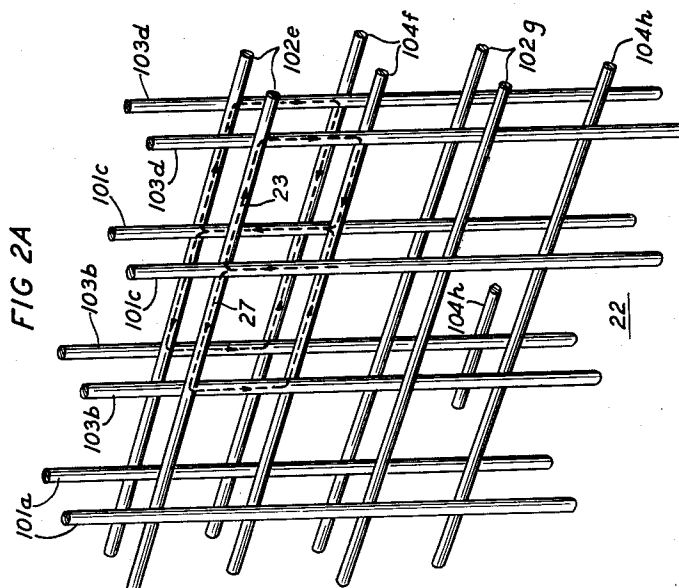
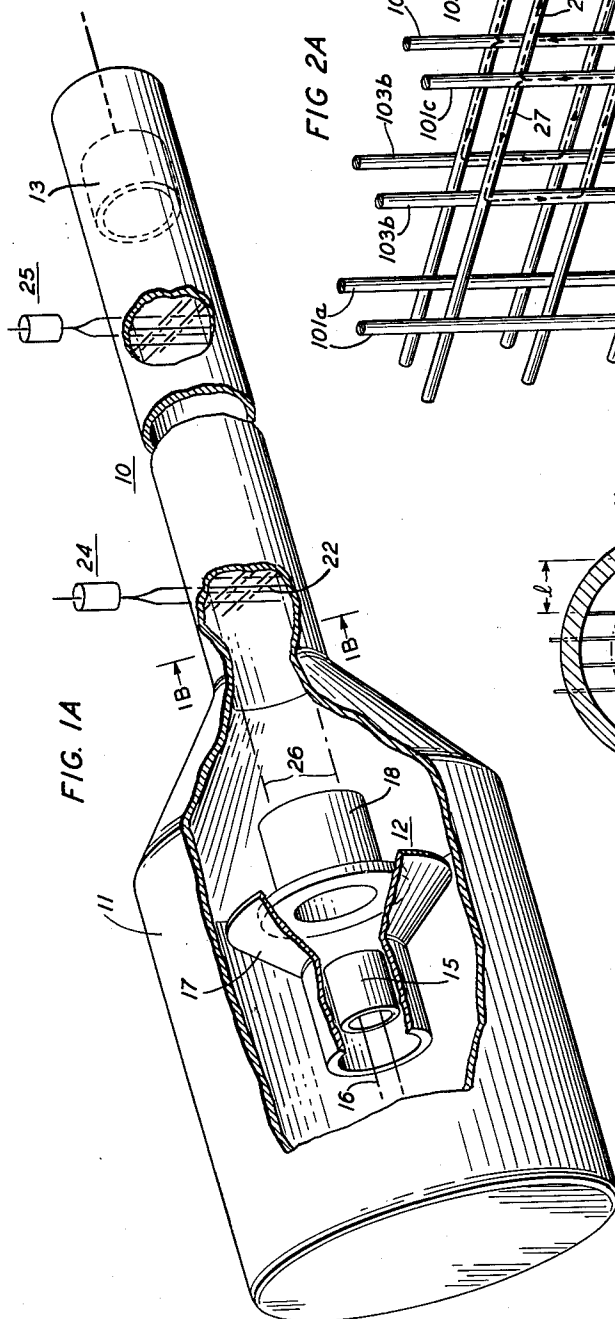
June 20, 1961

C. C. CUTLER

2,989,661

TRAVELING WAVE TUBE

Filed April 26, 1956



INVENTOR
C. C. CUTLER

BY
Arthur J. Tomiglieri
ATTORNEY

1

2,989,661

TRAVELING WAVE TUBE

Cassius C. Cutler, Gillette, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y.,
a corporation of New York
Filed Apr. 26, 1956, Ser. No. 580,908
14 Claims. (Cl. 315—3.6)

The present invention relates to a novel transmission circuit for use in a traveling wave tube.

Traveling wave tubes of various types are used for amplifying high frequency wave energy. Such amplification is achieved by propagating wave energy along a specially designed transmission circuit while projecting an electron beam along a path in coupling relation with the electric field of the propagating wave. Interaction between the electric field of the wave and the electron beam occurs, and when the velocity of propagation of the wave and the velocity of the electrons of the beam are approximately synchronous, the interaction produces an amplification of the wave. Because the maximum beam velocity obtainable in a practical tube is substantially less than the velocity of wave propagation along most transmission lines, it is necessary to provide a so-called slow wave transmission circuit for reducing the effective velocity of wave propagation.

Many such slow wave circuits have been proposed. Perhaps the most successful and certainly the most commonly used circuit comprises a conductive member, such as a wire or conductive tape, wound in the form of a helix. This circuit is characterized by structural simplicity and a capacity to operate over a wide frequency band. With such a circuit an electron beam is generally propagated along the axis of the helix and is maintained substantially synchronous with the axial velocity component of a wave propagating along the helix. Thus amplification is achieved.

A disadvantage of the helix transmission circuit for many purposes is that the amount of power obtainable from such a circuit is limited. This is particularly true for operation at very high frequencies since the dimensions of a helix suitable for use at such high frequencies are extremely small. Hence only a low current beam can be projected along the helix axis without striking the helix and thereby causing distortion to the amplified wave and damage to the fragile helix. Efforts to increase the power obtainable by arranging several helices in parallel have not been successful. These efforts have gone in two directions. The first is merely to arrange a bank of tubes in parallel, each of which employs a helix propagating circuit. This technique is not completely satisfactory because it is unwieldy and, further, because difficult phasing problems are introduced.

The second technique is to braze several identical helices together to form a unitary wave propagating structure of several helices in parallel. The circuit thus formed is then to be incorporated in a single tube. This latter technique has proved unsuccessful principally because of three factors. Firstly, it is now appreciated that such a structure is unsuited for a wave propagation circuit because the coupling between the several helices is so high that the several helices of the structure no longer act as independent circuits arranged in parallel, but, rather, as coordinate parts of a single circuit formed by the entire structure. Moreover, the resulting circuit thus formed is characterized by two phase velocities, one slower than and one faster than the phase velocity of the individual helices. Each of these phase velocities differs from the phase velocity of the individual helices by an amount dependent upon the degree of coupling between the helices. In the limiting case, that is, as the coupling

2

between the helices approaches unity, they approach zero and infinite velocity, respectively, and so the circuit is nonpropagating. However, even where the coupling remains low enough to permit propagation, neither of the two phase velocities is especially suitable for interaction with a beam and any interaction obtained is of a narrow band character. The second factor militating against successful operation in the brazed multiple helix arrangement is that discontinuities are disadvantageously introduced at the points where the helices were brazed together. Thirdly, the various helices must be dimensioned virtually identically in order to maintain constant phase relations between the electrical fields of the waves passing along the several helices, but such identical dimensioning is difficult to achieve in helix structures heretofore proposed.

It is a principal object of the present invention, therefore, to achieve satisfactory high power operation from a helix-like transmission circuit. A more particular object is to achieve such operation in a helix-like transmission circuit which may be readily fabricated.

To this end, a principal feature of the present invention is a wave propagating circuit for use in a traveling wave tube which essentially comprises a plurality of parallel extending helices, the pitches of adjacent helices of which are opposite in sense. The coupling between such oppositely pitched parallel extending helices can theoretically be zero. Thus each of the various helices acts as an independent circuit having the same phase velocity it would have in the absence of the other helices. In this way efficient interaction with the beam can be achieved.

A second feature of the present invention is a wave propagating structure of the above type formed by a plurality of wire-like conductive elements arranged in a matrix-like structure. The matrix structure in a preferred arrangement comprises a longitudinal succession of sets of straight vertical elements and straight horizontal elements arranged in a manner to simulate in effect a plurality of identical helical conductive paths longitudinally through the array. Actually, there is formed a plurality of identical conductive paths which are not truly helical only in that their shape in a projected end view is rectangular rather than circular. Moreover, the pitches of adjacent helical paths through the array are opposite in sense. The use of only straight elements considerably facilitates the ease of manufacture of the structure.

In an illustrative embodiment, the invention comprises a traveling wave tube including an electron gun and a target electrode spaced apart within an evacuated envelope for defining a path of electron flow within the envelope. A slow wave transmission circuit is located in coupling relation with the path of flow and extends along a substantial portion thereof. This circuit comprises a longitudinal succession of sets of vertical elements interleaved with a longitudinal succession of sets of horizontal elements in a manner to be described in detail hereinafter to achieve the effect of a plurality of parallel helical paths.

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

FIG. 1A is a perspective view of a traveling wave tube, shown partially cut away for purposes of illustration, which includes a slow wave transmission circuit designed in accordance with the present invention;

FIG. 1B is a cross-sectional view taken looking to the right along plane 1B—1B of FIG. 1A;

FIG. 2A is an expanded view of a fragment of the transmission circuit included in the tube of FIGS. 1A and 1B; and

FIG. 2B is a plan view of the transmission circuit fragment of FIG. 2A.

Referring now more particularly to the drawing, FIG. 1A shows a traveling wave tube 10 comprising an evacuated envelope 11, typically of glass or a nonmagnetic metal such as copper, enclosing an electron gun 12 for forming an electron beam and projecting the beam along an extended longitudinal path toward collector 13. The electron gun, as shown schematically, includes a cathode 15, heater 16, beam forming electrode 17, and accelerating anode 18. In practice, these elements are maintained in place by suitable supporting members, and there are provided lead-in conductors from suitable voltage sources for maintaining the various elements at appropriate potentials. In particular, the cathode customarily is biased to a potential slightly positive with respect to the beam forming electrode and appreciably negative with respect to the accelerating anode so that a beam of electrons will be projected toward the collector which is also biased positively with respect to the cathode. Additionally, in practice, apparatus is generally provided for establishing a magnetic field for maintaining the beam focused along this path. This apparatus may, for example, include a solenoid surrounding the beam along its length or a pair of oppositely poled permanent magnets spaced at opposite ends of tube 10 for providing a longitudinal magnetic field.

A transmission circuit 22, comprising a matrix-like array of straight horizontal and vertical wire elements shown in phantom in FIG. 1A, is positioned along a major portion of the beam path, such that each of the wave paths through the circuit is a plurality of operating wavelengths long. The details of the circuit will be discussed hereinafter. The circuit is maintained at a suitable positive D.-C. potential with respect to the cathode. Such potential fixes the velocity of the electrons in their flow past the circuit and is adjusted to achieve amplification of the wave traveling along the circuit.

The circuit is advantageously supported along its length by envelope 11, as can be seen from FIG. 1B. As indicated above, envelope 11 may be either glass or a non-magnetic conductor such as copper. In either event suitable connections can be made. When using glass, the wire-like elements of the circuit can be embedded in the glass. When a copper envelope is used, the elements can be brazed to the copper. A technique which has been found to be satisfactory when using a copper envelope is to form the envelope by use of a succession of washer-like elements. In the process, two wire-like elements were placed across the aperture in each washer and brazed at their ends to the washer. The washers were then packed together to form an envelope containing circuit 22, which will be viewed in greater detail in FIGS. 2A and 2B. An alternative technique for supporting the circuit, either in a glass or conductive envelope, is to adjust its dimensions to achieve a snug fit within the envelope and then to secure some part of it fixedly to the envelope to prevent rotation.

Where the circuit makes contact with the envelope for support, the use of a conductive material for the envelope will affect the characteristics of the circuit. In particular, with a conductive envelope the bandwidth of the circuit will be reduced since a low frequency cut-off will occur at a point where dimension *l* of FIG. 1B is approximately a quarter wavelength. Such a reduction in bandwidth, however, is accompanied by an increase in circuit interaction impedance, and hence in circuit gain, for operation near the cut-off frequency. Thus where extremely broad band operation is essential, a glass envelope is advantageously used. But where less stringent bandwidth requirements obtain, higher gain can be achieved by using a conductive envelope and operating near the cut-off frequency.

An enlarged view of a fragment of circuit 22 appears in FIGS. 2A and 2B. The details of the circuit can be seen more clearly in these figures. The fragment shown

comprises in turn with distance in the direction of beam flow: a pair of wire-like elements 101a, 101c in a first layer extending in a direction substantially vertical in the drawing; a second pair of elements 102e, 102g in a second layer extending in a direction substantially horizontal; a third pair 103b, 103d extending vertically in a third layer and interposed in a transverse direction with elements 101a and 101c; a fourth pair 104f, 104h extending horizontally in a fourth layer and interposed in a transverse direction with elements 102e and 102g. The elements of the fifth layer are aligned with elements of the first and the pattern of the first four layers is repeated. In practice the circuit typically will include approximately 40 layers, but may include more or less if more or less gain is desired.

The circuit accordingly comprises in a broadly descriptive sense a pattern of sets of four layers iterative in the direction of electron flow. Each layer comprises a plurality of spaced parallel straight wire-like elements lying in a plane transverse to the direction of beam flow. Elements in alternate layers are parallel to one another while elements in contiguous layers are perpendicular to one another. In a direction transverse to the path of electron flow, elements of the first layer are interposed between elements of the third layer and elements of the second layer are interposed between elements of the fourth layer.

The structure thus formed results in a plurality of conductive paths through circuit 22 each of which is essentially helical except that their shape in a projected end view would form a square rather than a circle. One of these paths is shown in FIG. 2A by dashed line 23 which starts along the first element 101c, then continues right along element 102e, down along element 103d, left along element 104f, up along the succeeding element 101c, and so forth through the array. The sense of the pitch of the helical-like path thus formed is clockwise in the figure. An adjacent path, wound in a counterclockwise sense, is shown by dashed line 27. Seven other similarly helical-like paths can be traced through the circuit, adjacent ones of which are wound in opposite sense. In the figure, the shape of each of the helical-like conductive paths in a projected end view would form a square. Alternatively, these shapes may be rectangular, for example, where the spacing between the various vertical elements is different from the spacing between the various horizontal elements, or parallelograms where the elements of successive layers are not horizontal and vertical but cross at an angle other than 90°. Additionally, by appropriate modifications the shapes may take the form of any regular geometric figure having an even number of sides, for example a hexagon, and yet maintain the helix-like paths through the array.

A wave to be amplified is transferred to each of the roughly helical paths by coupling in-phase to elements 101a, 101c of the first layer. This can be seen more clearly by referring back to FIG. 1A where coaxial line 24 serves to transfer a signal wave in-phase to the two wire-like elements at the upstream end of the circuit. The signal circuit current of the wave thus supplied is divided into several portions, each of which passes along a different one of the helical-like paths through the circuit. Each of the components is amplified in passing from left to right along the circuit and the several components are recombined at the two wire-like elements furthest downstream along the circuit. The amplified wave is then transferred to an external circuit (not shown) via coaxial line 25, whose center conductor is connected to the two elements furthest downstream. The amplification is achieved by interaction between the various signal wave components and the electron beam whose outer periphery is shown by dashed lines 26 of FIGS. 1A and 1B. Some electrons of this beam will strike the wire-like elements at the upstream end of circuit 22 and the remainder of the electrons will continue along the longitudinal passages

through the circuit. The circuit may readily be made sufficiently rugged to withstand the electrons impinging thereon, particularly where the circuit is supported within, and has good heat conduction paths to, a conductive envelope. Nevertheless, the electron impingement can be minimized by inserting a conductive intercepting grid between the electron gun and the circuit. The grid will advantageously have substantially the same configuration as circuit 22 viewed from one end, as in FIG. 1B. Hence it will serve to intercept the electrons which would in its absence strike the circuit.

In circuit 22 there is no problem of introducing an undesired phase shift between the various components of the wave energy whose circuit currents pass along the different helical paths through the circuit. This is so because the various helical paths of the circuit can readily be made identical. Additionally, these helical paths are excited symmetrically by the coaxial line input connection, and further the various helices are interconnected at various points along their respective lengths. This interconnection assists in maintaining constant phase conditions along the several helices.

It is to be noted that the pitches of adjacent helical paths through the matrix-like array 22 are opposite in sense. It is this characteristic, as discussed above, which ensures the absence of undesired coupling between adjacent helices and thus makes possible wave propagation by the circuit at a phase velocity suitable for interaction with the beam. Moreover, without the undesired coupling, each of the several helices serves as a substantially independent propagating circuit having a phase velocity substantially the same as it would be in the absence of the other helices. Thus if different signals were applied to the different helical paths through the matrix-like array, each of the signals would be amplified. In this case, separate input and output connections would be provided to each of the different helical paths and a separate electron beam projected axially through each such path. In such an arrangement, the array serves as a multi-channel device. For facilitating separate excitation of the different helical paths in a multi-channel device, it will be desirable in some cases to separate the helices in space while maintaining the pitch of adjacent ones opposite in sense.

It is understood that the embodiment described is merely an illustrative example of the present invention. Other embodiments can be made by those skilled in the art in the light of this disclosure without departing from the spirit and scope of this invention. Additionally, modifications of the illustrative embodiment can likewise be made. In particular, circuit 22 need not be supported by the tube envelope; other techniques known in the art can be used, such as supporting rods of dielectric material extending longitudinally along the circuit parallel to the electron beam axis. Further, the circuit has been described as comprising a succession of layers each of which includes two wire-like elements. In an alternative arrangement each layer may include a greater number of wire-like elements. Additionally, adjacent layers of wire-like elements have been described as being perpendicular to each other but, if desired, they may be disposed at some other angle.

What is claimed is:

1. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, a slow wave circuit for propagating an electromagnetic wave in coupling relation with said beam comprising a plurality of wire-like conductive elements arranged in a matrix-like array, the array comprising a longitudinal succession of sets of vertical elements interleaved with a longitudinal succession of sets of horizontal elements, alternate sets of vertical elements being aligned longitudinally and adjacent sets being displaced from each other in a horizontal direction, and alternate sets of horizontal elements likewise being aligned longitudinally and adjacent sets thereof being displaced from each other in a

vertical direction, whereby there is formed a plurality of parallel continuously extending roughly helical conductive paths through the matrix-like array, an electron source, and means for directing electrons from said source into a beam for passage in a longitudinal direction through said array in energy coupling relation with the helical paths.

2. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and a slow wave circuit for propagating an electromagnetic wave in coupling relation with said beam comprising a longitudinal succession of contiguous layers of wire-like elements, each layer including a plurality of such elements extending in a direction parallel to each other and substantially perpendicular to and in contacting relation with each of the elements of adjacent layers forming a plurality of parallel extending helix-like conductive paths.

3. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and a slow wave circuit for propagating an electromagnetic wave in coupling relation with said beam comprising a longitudinal succession of contiguous layers of wire-like elements, each layer including a plurality of such elements extending in a direction substantially parallel to each other and at a substantial angle and in contacting relation with each of the elements of adjacent layers, and the elements of alternate layers being parallel but offset from each other in a transverse direction for forming a plurality of substantially helical paths through the circuit.

4. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and a slow wave circuit for propagating an electromagnetic wave in coupling relation with said beam comprising a longitudinal succession of contiguous layers of wire-like elements, each layer including a plurality of such elements extending in a direction parallel to each other and substantially perpendicular to and in contacting relation with each of the elements of adjacent layers, and the parallel extending elements of alternate layers being offset from each other in a transverse direction for forming a plurality of substantially helical paths through the circuit.

5. An interaction circuit for propagating an electromagnetic wave in a longitudinal direction comprising a plurality of contiguous sections forming an iterative pattern, each section of which includes four contiguous layers of transversely extending wire-like elements, all of the elements in respective layers being in contacting relation with each of the elements in adjacent layers, the elements of the first and third layers extending parallel to each other in a predetermined direction and the elements of the second and fourth layers extending parallel to each other and at a substantial angle with the elements of the first and third layers, the elements of the first layer being offset from the elements of the third layer in a direction perpendicular to said predetermined direction, and the elements of the second layer being offset from the elements of the fourth layer in said predetermined direction.

6. The combination of elements set forth in claim 5 wherein the elements of the first and third layers are substantially perpendicular to the elements of the second and fourth layers.

7. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and slow wave circuit means for propagating an electromagnetic wave in coupling relation with said beam comprising a plurality of straight wire-like elements contiguously ar-

ranged and interleaved to form a plurality of parallel extending helix-like conductive paths, the pitches of adjacent helix-like paths being opposite in sense.

8. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and means for forming a plurality of parallel contiguously extending conductive paths for propagating electromagnetic wave energy in coupling relation with said beam, each of which describes a helix-like pattern whose end projection is a parallelogram, one side of which is common to the parallel extending path adjacent thereto.

9. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and a slow wave circuit for propagating an electromagnetic wave in coupling relation with said beam comprising means forming a plurality of parallel contiguously extending helix-like conductive paths, the pitches of adjacent helix-like paths being opposite in sense with a portion of successive turns thereof being common to adjacent ones of said parallel extending paths.

10. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and slow wave circuit means for propagating an electromagnetic wave in coupling relation with said beam comprising a plurality of helix-like conductive elements, the axis of each being parallel to but displaced from that of the others, the various helix-like conductive elements extending contiguous to each other and being joined at points along their lengths to form a unitary structure, each of the helix-like elements of the structure being identical in configuration but the pitches of adjacent elements being opposite in sense.

11. An interaction circuit for propagating an electromagnetic wave comprising a plurality of sections forming an iterative pattern, each section of which includes four layers of transversely extending wire-like elements, all of the elements in respective layers being in contacting relation with each of the elements in adjacent layers, elements in alternate layers being parallel to one another and elements in contiguous layers being substantially perpendicular to one another, and elements of the first layer being interposed with elements of the third layer and elements of the second layer being interposed with elements of the fourth layer.

12. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path and means for forming a plurality of parallel extending conductive paths for propagating electromagnetic wave energy in coupling relation with said beam, said last-mentioned means comprising a succession of contiguous sections forming an iterative pattern, each section of which includes four contiguous layers of transversely extending wire-like elements, all of the elements in respective layers being in contacting relation with each of the elements in adjacent layers, the elements of the first and third layers extending parallel to each other in a predetermined direction and the elements of the second and fourth layers extending parallel to each other and at a substantial angle with the elements of the first and third layers, the elements of the first layer being offset from the elements of the third layer in a direction perpendicular to said predeter-

mined direction, and the elements of the second layer being offset from the elements of the fourth layer in said predetermined direction whereby said elements describe a helix-like pattern whose end projection is a parallelogram.

13. In a device which utilizes the interaction between an electromagnetic wave and an electron beam for amplifying the wave, an electron source, means for directing electrons from said source along an extended path, and a slow wave circuit means for propagating an electromagnetic wave in coupling relation with said beam, said last-mentioned means including a succession of contiguous sections forming an iterative pattern, each section of which includes four contiguous layers of transversely extending wire-like elements, all of the elements in respective layers being in contacting relation with each of the elements in adjacent layers, the elements in alternate layers being parallel to each other and elements of adjacent contacting layers being substantially perpendicular to each other, elements of the first layer being interposed with elements of the third layer and elements of the second layer being interposed with elements of the fourth layer whereby there is formed a plurality of parallel extending roughly helical conductive paths, the axis of each being parallel to but displaced from that of the others and the pitches of adjacent helix-like elements being opposite in sense.

14. A slow wave structure for use in connection with devices for translating electromagnetic waves comprising a helix-derived structure for guiding said electromagnetic wave, said structure comprising a plurality of linear conductors lying in parallel planes, said conductors forming two groups, each of the conductors in one group being parallel to one another, the conductors of one group being in spaced quadrature relationship to the conductors of the other group, the conductors of each of said groups forming a plurality of even and odd-numbered sets, the conductors of each set lying in a plane and successive conductors in said plane being laterally displaced from one another by a predetermined distance, the conductors of one set of one group being conductively interleaved between conductors of successive sets of the other group, the conductors of the odd-positioned sets of each group lying in a respective set of planes perpendicular to the planes of said sets, the conductors of the even-positioned sets of each group lying in a respective set of planes perpendicular to the planes of said sets, the number of planes in a set of planes being equal to the number of conductors in a set of conductors, adjacent planes of even and odd-positioned sets of conductors of one group of conductors being spaced apart by a predetermined distance substantially one-half said first-mentioned predetermined distance, said structure extending for many wavelengths at the frequency of operation thereof in a direction perpendicular to the plane of said conductors.

References Cited in the file of this patent

UNITED STATES PATENTS

2,708,236	Pierce	May 10, 1955
2,746,036	Walker	May 15, 1956
2,800,604	Beaver	July 23, 1957
2,801,361	Pierce	July 30, 1957
2,806,973	McEwan et al.	Sept. 17, 1957
2,812,468	Robertson	Nov. 5, 1957
2,823,332	Fletcher	Feb. 11, 1958

FOREIGN PATENTS

691,900	Great Britain	May 20, 1953
1,119,661	France	Apr. 9, 1956