Aug. 9, 1960 A. ASHKIN 2,948,828

TRAVELING WAVE TUBE INTERACTION CIRCUIT

Filed Nov. 21, 1956 4 Sheets-Sheet 1

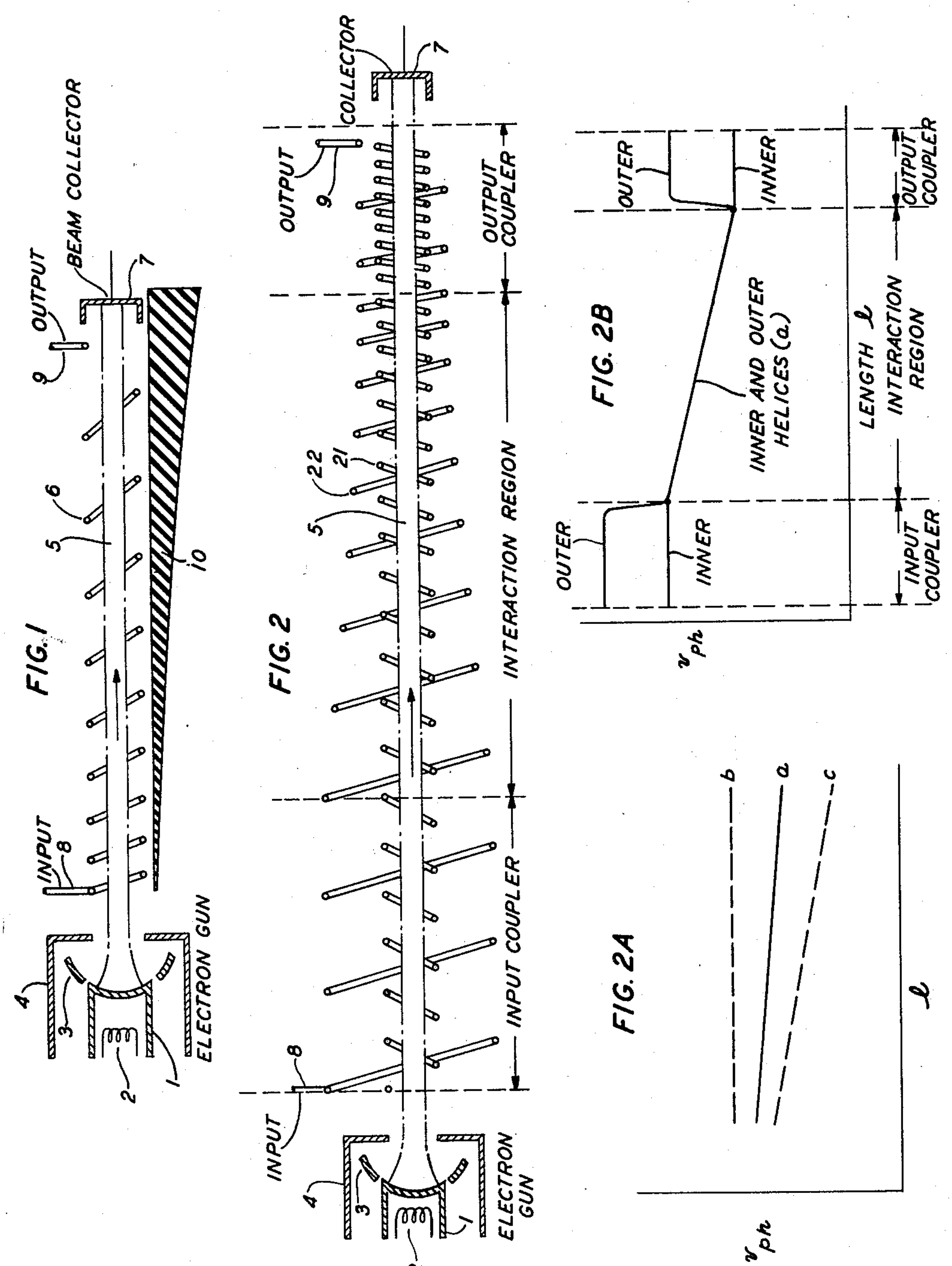

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FIG. 3

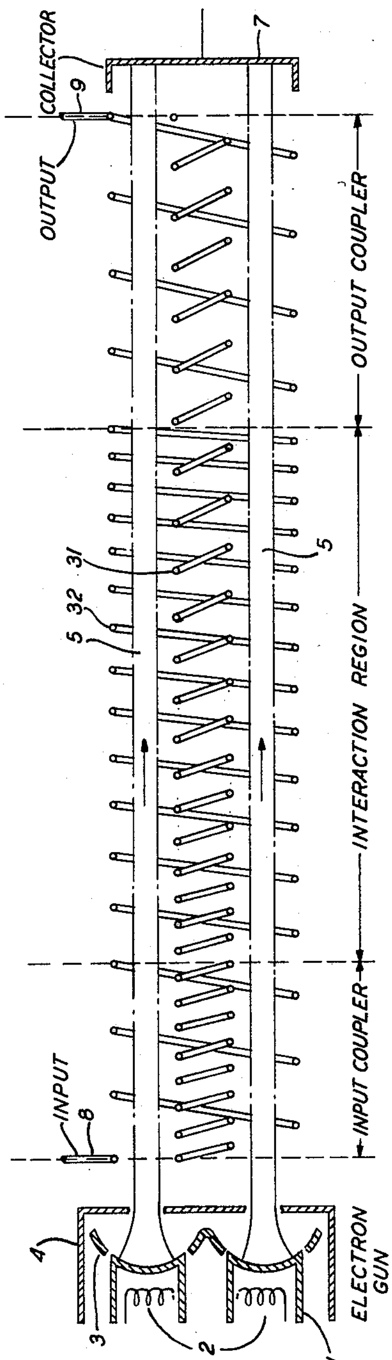


FIG. 3B

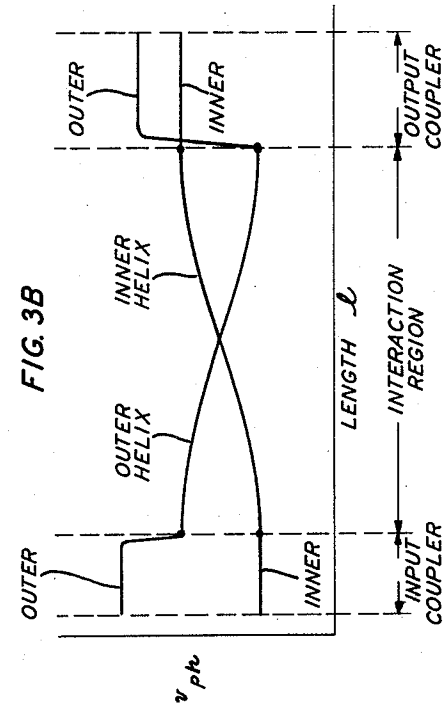
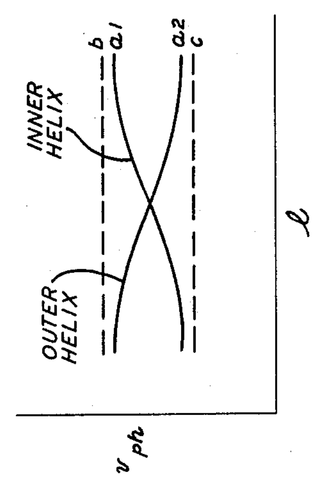


FIG. 3A



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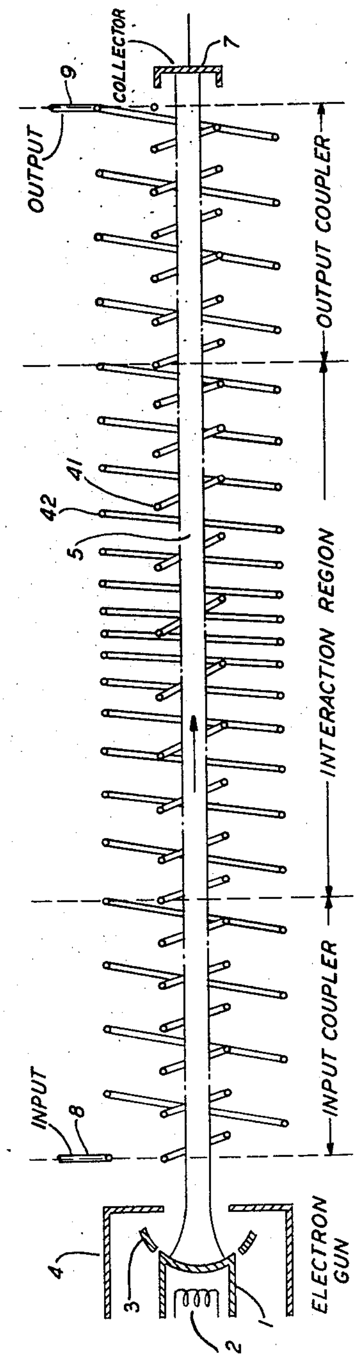

FIG. 4

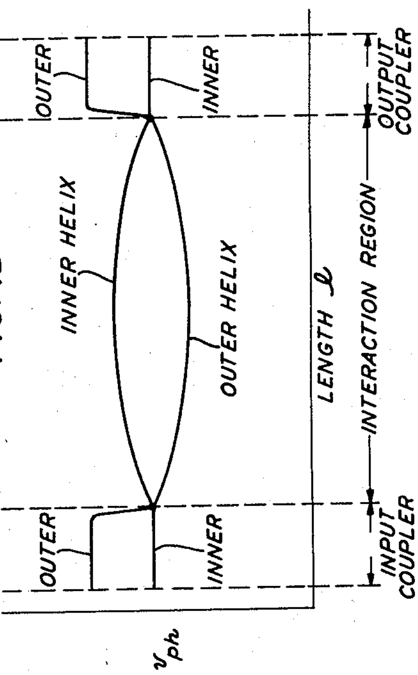

FIG. 4B

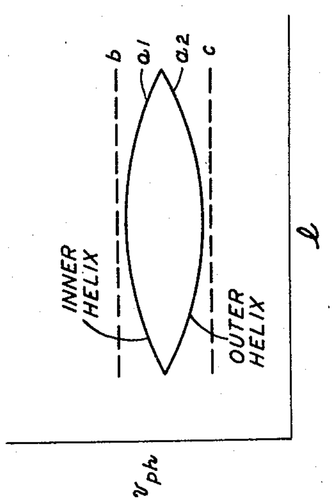

FIG. 4A

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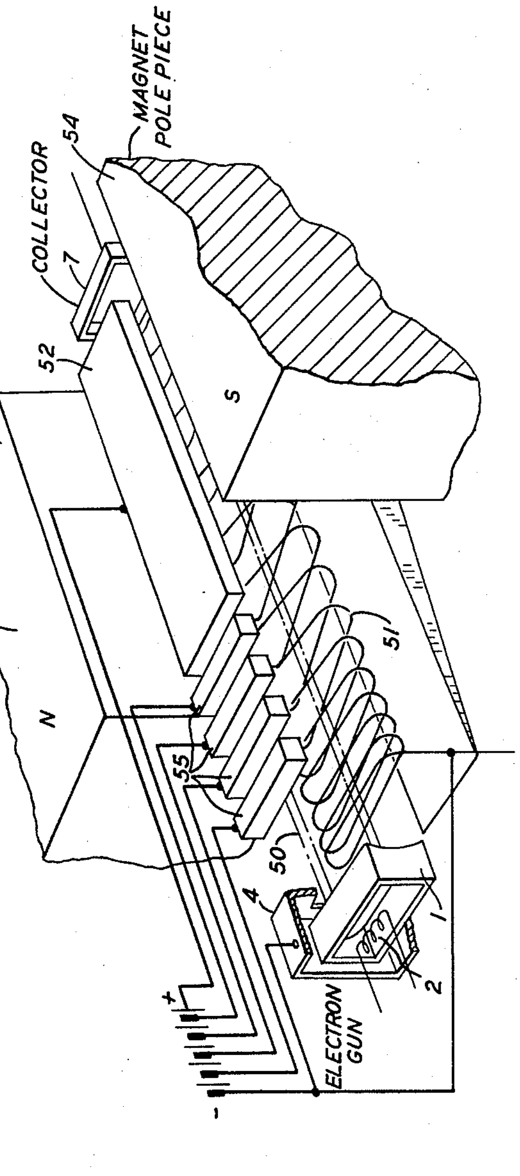

FIG. 5

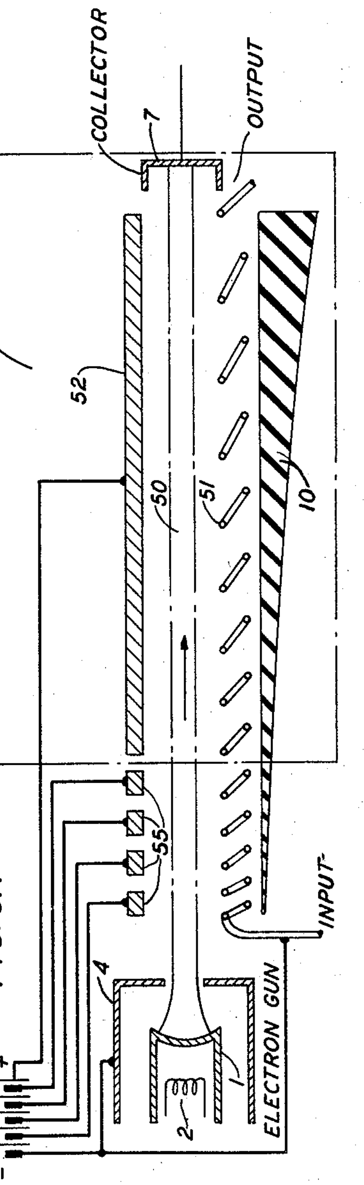

FIG. 5A

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TRAVELING WAVE TUBE INTERACTION CIRCUIT

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16 Claims. (Cl. 315—3.6)

This invention relates to traveling wave tubes, which may be described as electron tubes utilizing a wave transmission circuit for propagating electromagnetic waves in field coupling relation with an electron beam to permit interchange of energy between the transmission circuit and the electron beam along several wavelengths of the circuit. It relates particularly to such tubes which employ in the transmission circuit a helical wave path to reduce the electromagnetic wave velocity along the path of the electron beam so that it is substantially synchronous with the beam.

One of the difficulties encountered in attempting to use such tubes as high power amplifiers is the production of unwanted backward wave oscillations at high beam currents. The production of backward wave oscillations in a traveling wave tube is quite well understood and is discussed in an article by H. Heffner, "Analysis of the Backward Wave Traveling Wave Tube," Proceedings of the I.R.E., volume 42 (June 1954), pages 930 through 937. These oscillations can occur in a helix type of tube, because the helix, where uniformly wound, is actually a periodic structure and with a helix of uniform pitch, the spaces between adjacent turns can be regarded as interacting gaps periodically located along the path of the electron beam which permit spatial harmonic interaction between the beam and the helix circuit. Due to the fact that the impedance to the beam is lower for the sapital harmonic mode of operation than for the fundamental mode, harmonic operation does not occur in helix type traveling wave tubes as ordinarily used employing relatively low electron beam current. However, when, for the purpose of increasing the power output the beam current is increased sufficiently, the interaction with the circuit may become great enough to permit the harmonic mode of operation, and result in objectionable backward wave oscillation.

It is the object of this invention to provide means in the helix type of traveling wave tube for preventing interaction which will cause the objectionable operation in the spatial harmonic mode without impairing operation in the desired fundamental mode.

This is accomplished, according to the invention, by utilizing in the wave transmission circuit a helix wound with a continuously varying pitch in the region of interaction with the electron beam to destroy the periodicity of the interacting gaps between adjacent turns and so discourage operation in the harmonic mode with consequent building up of backward wave oscillations. In order to retain efficient operation of the tube in the fundamental mode, the effect of the variation in the pitch of the helix upon the wave velocity therealong is counteracted by continuously varying the loading of the helix along its length to restore the desired normally constant phase velocity characteristic along the interaction region. Any means suitable for appropriately varying the loading of the helix may be employed. At present, it appears preferable to use either dielectric material properly distributed along and in the field of the helix, or a second

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helix extending along and variably coupled to the first helix having the variable pitch.

The invention and its application in specific embodiments will be better understood from the following description and the accompanying drawings of which:

Fig. 1 is a schematic drawing illustrating an embodiment of the invention in a traveling wave tube utilizing in the wave transmission circuit a helix of uniform diameter and varying pitch variably loaded along its length by means of dielectric material to maintain uniform phase velocity along the circuit;

Fig. 2 is a schematic drawing illustrating an embodiment of the invention in a traveling wave tube utilizing in the wave transmission circuit a first (inner) helix of uniform diameter and varying pitch which is variably loaded along its length by means of a second (outer) helix which is coaxial with the first, has a varying pitch and is of varying diameter for variable coupling to the first helix to maintain uniform phase velocity along the circuit in the principal region of interaction with the electron beam;

Fig. 2A is a diagram indicating relative phase velocities at points along the lengths of the helices of Fig. 2 in the principal interaction region when the helices are separated from each other (uncoupled) and also under the two possible modes of operation when coupled as in Fig. 2;

Fig. 2B is a diagram indicating relative phase velocities along the lengths of the helices of Fig. 2 in both the coupling and the principal interaction regions when the helices are separated from each other (uncoupled);

Fig. 3 illustrates schematically an embodiment of the invention in a traveling wave tube utilizing a tubular electron beam and in the wave transmission circuit a first (inner) helix of uniform diameter and varying pitch variably loaded along its length by means of a second (outer) helix coaxial with the first and of uniform diameter and varying pitch for variable coupling to the first helix to maintain uniform phase velocity along the circuit in the principal region of interaction with the electron beam;

Figs. 3A and 3B are diagrams similar to Figs. 2A and 2B, but indicating the relative phase velocities at points along the lengths of the helices of Fig. 3;

Fig. 4 illustrates schematically another embodiment of the invention in a traveling wave tube utilizing an axial electron beam, and in the wave circuit first and second uniform diameter variable pitch helices coupled as in Fig. 3 to maintain uniform phase velocity. However, whereas in Fig. 3 the pitches of the inner and outer helices increase and decrease respectively with the length along the entire length of the principal interaction region, and the uncoupled phase velocities are similar in the center, in Fig. 4 the pitches of the inner and outer helices increase and decrease, respectively, with the length from one end to the center of the principal interaction region, and then decrease and increase, respectively, with the length from the center of the principal interaction region to the other end, and the uncoupled phase velocities are similar at the two ends;

Figs. 4A and 4B are diagrams similar to Figs. 3A and 3B but indicating relative phase velocities at points along the lengths of the helices of Fig. 4; and

Figs. 5 and 5A illustrate in perspective and longitudinal section, respectively, an embodiment of the invention in a magnetron type of traveling wave tube. Here is shown a single flattened variable pitch helix variably loaded by means of a tapered dielectric block to maintain constant phase velocity along the length of the helix, as is shown in Fig. 1.

To simplify the drawings, the usual vacuum tight envelope required, potential sources, the commonly employed electron beam focusing means extending along the beam path (except in Fig. 5), and energy absorbing means associated with the circuit in the interaction region to prevent oscillations due to reflected energy are not shown.

The various figures, illustrative of the several embodiments of the invention described, are intended merely to clarify the descriptions and consequently do not indicate sizes or proportions. For instance, the tubes would ordinarily be much more elongated than shown, the length indicated as "interaction region" would be much longer in proportion to the lengths of the couplers than is shown, and the diagrams showing relations between phase velocity and length along the helices indicate only the character of the variations, not actual dimensions or slopes. Furthermore, the portion of the length of each tube marked "interaction region" is the principal interaction region where the wave phase velocity is kept constant and virtually all of the amplification takes place. The relatively small interaction in the coupler regions is neglected.

Referring now to Fig. 1, internal elements of a beam-helix type of traveling wave tube, according to one embodiment of the invention, are illustrated schematically in the form of a longitudinal section. From the electron gun comprising cathode **1**, heater **2**, focusing and accelerating electrodes **3** and **4**, the electron beam **5** is projected along the axis of and in coupling relation with the helix wave transmission circuit **6** to the electron collector **7**. The input and output connections to the helix are indicated at **8** and **9**, respectively. In accordance with the invention, the helix **6** is wound with continuously varying pitch to destroy the periodicity of the interacting gaps between turns, and thereby discourage the building up of the undesirable backward wave oscillations. Further in accordance with the invention, a block of dielectric material **10** tapered gradually but not necessarily uniform with length is disposed along and coupled to the helix to provide loading of the helix in varying amount along its length to compensate for the effect upon phase velocity of the varying pitch of the winding. This loading is so varied that the phase velocity of wave propagation along the the length of the helix is substantially uniform in spite of the varying winding pitch. Thus, by varying the helix winding pitch, the unwanted backward wave oscillations are avoided and, by compensating for such variations to maintain constant wave phase velocity, the normal functioning of the traveling wave tube is retained.

It may be noted that while the desired variation in loading by the dielectric material **10** is shown as being accomplished by tapering the block of dielectric material, it may be had also by other suitable means, such as by positioning of the block or by varying the composition of the material. Also, the direction of the tapering of the block of dielectric **10** and of the variation in pitch of the helix **6** may be the reverse of what is shown in the figure.

Fig. 2 is an illustration showing in the same general manner as Fig. 1 another embodiment of the invention in a beam-helix type of traveling wave tube. Where appropriate, designations the same as in Fig. 1 are employed. In this embodiment the varying loading of the inner helix **21**, having gradually decreasing pitch along the length of the tube indicated as "interaction region," is had by means of an outer helix **22**, preferably wound oppositely to the winding of helix **21** to enhance the mutual coupling. Terminations not shown may be attached to the otherwise free ends of the inner helix **21**. Helix **22** also has a gradually decreasing pitch along the interaction region, but has additionally a gradually changing diameter to provide varying coupling between the two helices in that region. This coupling is adjusted to obtain a constant phase velocity along the interaction region.

The gradually decreasing pitch of the inner helix **21** corresponds to a gradually decreasing phase velocity in the uncoupled state, that is, separated from the influence of helix **22**. The portion of the outer helix **22** in the interaction region also having gradually decreasing pitch likewise has a decreasing phase velocity in the uncoupled state or when separated from the influence of helix **21**. The portions of helices **21** and **22** in the interaction region are designed to have the same phase velocity characteristic when uncoupled or separated from each other. That is, at each point along the length in the interaction region l, the two helices have the same phase velocity when uncoupled, as is indicated by the solid line graph a of Fig. 2A.

Such a system of two coupled helices has two modes of wave propagation, one faster than that of the individual helices and one slower. The upper and lower dotted line graphs b and c of Fig. 2A show phase characteristics typical of the faster and slower modes of propagation, respectively, of the system consisting of the two helices **21** and **22** coupled together as shown in Fig. 2. Fig. 2A thus shows three phase velocity characteristics typical of the helices of Fig. 2, phase velocity being plotted against length l along the helices in the region indicated "interaction region" in Fig. 2 where both helices have varying pitch.

The coupling between the two helices may be adjusted so that the phase velocity of either the faster or the slower mode of propagation is constant along the length l. In this particular illustrative embodiment, the coupling between the two helices is adjusted so that the phase velocity of the faster mode of the coupled system is constant along the length of the interaction region, as is shown by the graph b of Fig. 2A. In this manner, the desired objective of maintaining constant phase velocity along the interaction region while at the same time employing a helical wave circuit with non-uniform pitch to avoid unwanted backward wave oscillation is attained. To obtain this result in operation it is, of course, necessary that the coupled helix system operate in the desired mode. In this instance, it is therefore necessary to provide means to launch the fast mode at the input of the helices and to extract the power in the fast mode at the output end. This may be done by means of what have been termed "step couplers," which are short lengths of appropriately coupled helices, attached to each end of the portions of the two coupled helices located in the interaction region indicated in Figs. 2 and 2B. It may be noted in Fig. 2 that the short lengths of helices comprising the couplers are actually extensions of and parts of the coupled helices **21** and **22**. Such couplers are described in U.S. Patent 2,885,593, issued May 5, 1959, of J. S. Cook.

Cook refers to each such coupler as a transducer section, and teaches that a desired mode of propagation may be excited in a pair of coupled transmission lines by associating therewith a properly designed transducer section of lines as an extension of the pair of coupled lines, and applying an input wave to the end of one of the two lines forming the transducer section. The two lines forming the transducer section must be chosen to have different average characteristic phase propagation constants. The faster of the two normal modes of the coupled transmission lines may then be launched therein by exciting the component line of the input transducer section having the faster average phase velocity, and conversely, the slower normal mode may be launched by exciting the component line of the input transducer section having the slower average phase velocity. Similarly, from reciprocity considerations, the faster of the two lines forming an output transducer section will be excited selectively when the faster normal mode is in the main coupled line, and the slower line when the slower mode is in the main coupled line. Reference can be made to this above-cited patent for a detailed description of the principles of operation and design of these "couplers" or "transducer sections."

The couplers indicated in Figs. 2 and 2B are in accordance with the teachings of the Cook patent referred to above. They are shown to illustrate a method of operating the system of coupled helices (**21** and **22**) in the proper mode of wave propagation, that is, the mode for which the phase velocity has been made constant (such as indicated by the graph *b* of Fig. 2A). It may be seen from Fig. 2B, which shows typical variations in phase velocity along the helices (when uncoupled) in the interaction and coupler regions, that the coupler sections of helix **22** (the outer helix) have higher phase velocity characteristics than the coupler sections of helix **21** (the inner helix), and therefore, to operate the system in the faster mode (for which the phase velocity has been made constant), input and output connections are made to the coupler sections of the outer helix. If it were desired to operate the system in the slower mode of wave propagation, appropriately different coupler sections or connections thereto would be employed as taught by Cook in the aferomentionad patent.

Fig. 3 illustrates in the same general manner as Fig. 2 another embodiment of the invention in a traveling wave tube utilizing two coupled helices, preferably wound oppositely, to effect variable loading to maintain constant wave phase velocity along the interaction region. Where appropriate, designations are the same as for Figs. 1 and 2. However, in this figure the cathode and other elements of the electron gun are arranged to project a tubular beam of electrons **5** through the annular space between the two coupled helices **31** and **32** to the collector **7**, although an axial beam as shown in Fig. 2 could be used. In this embodiment is a constant diameter inner helix **31** with pitch and phase velocity gradually increasing along its length in the uncoupled state. The outer helix **32**, however, has a pitch and phase velocity decreasing with length along the interaction region and, unlike the outer helix of Fig. 2, it has a constant diameter. Since the separation of the phase velocities of these helices (when uncoupled) varies with length, the effective coupling varies with length too when they are coupled together. This coupling is weakest at the ends of the interaction region and strongest in the middle. The variations of the phase velocity of each of the helices can be adjusted to achieve a situation in which the coupled system has a mode of wave propagation with constant phase velocity whereby, according to the invention, efficient traveling wave tube operation may be had together with the advantage of non-uniform helix pitch in preventing backward wave oscillation.

Fig. 3A illustrates typical phase velocity variations along the length *l* (the interaction region) of the inner and outer helices **31** and **32**. The solid line graphs *a1* and *a2* show variations of phase velocity along the two helices when uncoupled, and the dotted line graphs *b* and *c* show phase velocity variations along the two helices for the faster and slower modes of wave propagation when the helices are coupled together, as in Fig. 3. The phase velocity may be and is shown constant for both modes of propagation.

In order to operate the Fig. 3 embodiment in the desired mode, step-couplers or transducer sections are shown at each end of the interaction region, as has been explained in connection with the description of Fig. 2.

Typical variations in phase velocity along the helices in the coupler and the interaction regions when the helices are uncoupled are shown in Fig. 3B. The outer helix portions of the couplers have the higher phase velocities, and to these the input and output connections are made in Fig. 3 to operate the system in the faster velocity mode of wave propagation. As mentioned in the description of Fig. 2, terminations not shown may be connected to the otherwise free ends of the inner helix **31**.

Fig. 4 illustrates an embodiment of the invention which, like Fig. 3, employs two helices, each with constant diameter. Here, however, along the length of the interaction region, the pitch and phase velocity of the inner helix increase and then decrease to the initial value, while the pitch and phase velocity of the outer helix along that region decrease and then increase to the initial value. As with Fig. 3, when coupled together, these sections of helix can have modes of propagation with constant phase velocity.

Where appropriate, the designations on Fig. 4 are the same as for the previous figures, and it may be noted that an axial electron beam is shown as in Fig. 2, although a tubular beam as in Fig. 3 could be used. The inner and outer coupled helices are designated **41** and **42**, respectively. As with Fig. 3, since the separation of the phase velocities of these two helices (when uncoupled) varies with length, the effective coupling varies with length too when they are coupled together. Here, however, the coupling is strongest at the ends of the interaction region, and weakest in the middle. Again (as with Fig. 3), the variations of the phase velocity of each of the helices can be adjusted so that the coupled system has a mode of wave propagation with constant velocity whereby the objective of the invention may be achieved.

Fig. 4A illustrates typical phase velocity variations along the length *l* (the interaction region) of the inner and outer helices **41** and **42**. The solid line graphs *a1* and *a2* show variations of phase velocity along the two helices uncoupled, and the dotted line graphs *b* and *c* show phase velocity variations along the two helices for the faster and slower modes of wave propagation when the helices are coupled together, as in Fig. 4.

To operate the Fig. 4 embodiment in the desired mode, step-couplers, or transducer sections, are shown at each end of the interaction region, as has been explained in connection with the descriptions of Figs. 2 and 3. Typical variations in phase velocity along the helices in the coupler and interaction regions when the helices are uncoupled are shown in Fig. 4B. The outer helix portions of the couplers have the higher phase velocities, and these are used for the input and output connections in Fig. 4 to operate the system in the faster velocity mode of wave propagation. As previously mentioned, terminations not shown may be connected to the otherwise free ends of the inner helix **41**.

Figs. 5 and 5A illustrate an embodiment of the invention in a linear magnetron type of traveling wave tube employing a helix type of wave propagating circuit. A flattened helix **51** is shown as an example. In accordance with the invention, the pitch of the helix is varied continuously along its length, and further by way of example, a tapered block of dielectric material **10** is located along and in proximity to the helix to variably load the helix along its length to compensate for the varying pitch and so maintain constant wave phase velocity therealong, as was shown in Fig. 1 and described in connection therewith. Other types of helix structures with variable pitch and constant phase velocity, including those of Figs. 2, 3 and 4 which have been described, may be incorporated into a magnetron, crossed electric and magnetic field, type of amplifier.

In Figs. 5 and 5A, the flat electron beam **50** is projected from the cathode **1** of the electron gun to the collector **7** along the helix **51** between the helix and the oppositely polarized plate **52**. The magnetic field producing means, pole pieces **53** and **54**, produce a magnetic field in the space between plate **52** and the helix which is perpendicular to the electric field there and to the direction of travel of the electron beam **50**. The region of interaction between the electron beam **50** and the helix **51** is along the space between plate **52** and the helix. The focusing strips **55** are maintained at different direct voltages with respect to the helix **51**, and are adjusted to counteract the variable magnetic force in the fringe field region by maintaining the proper ratio of electric to magnetic field in the fringe magnetic field. This means for focusing an electron beam prior to its entrance into the magnetic field of the interaction space in a linear magnetron is described in my U.S. Patent 2,843,793, issued July 15, 1958. While it is part of the illustrative magnetron structure, it is not related to the invention of the instant application, which briefly stated, relates to a varying pitch constant phase velocity helical type of interaction circuit for a traveling wave tube.

It is to be understood that the several arrangements which have been described are merely illustrative of the invention, and that other modifications may be devised by one skilled in the art without departing from the spirit and scope of the application. In particular, the principles described may be extended to traveling wave tubes which employ other forms of slow wave circuits which like the helix do not involve spatial harmonic operation and so do not need to be periodic in structure, but which ordinarily are made periodic in structure to facilitate achieving a constant phase velocity.

What is claimed is:

1. In a traveling wave tube utilizing a wave transmission circuit for propagating electromagnetic waves in field coupling relation with an electron stream, the combination including a transmission circuit comprising a helix portion having predetermined variations in pitch along its length in the region of said field coupling relation, and means coupled to said helix portion for counteracting the effect of the variations in pitch upon the uniformity of phase velocity of a wave propagated therealong.

2. A device according to claim 1 in which the variations in pitch of the said helix portion are substantially uniform with length therealong.

3. A device according to claim 1 in which the pitch of the helix portion increases in a single direction therealong.

4. A device according to claim 1 in which the pitch of the helix portion increases in one direction therealong in one part of the length and in the other direction therealong in another part of the length.

5. A device according to claim 1 in which the means for counteracting the effect of variations in pitch of the helix portion upon the uniformity of phase velocity comprises a member of dielectric material coupled to the helix portion and electrically loading it variably along its length.

6. A device according to claim 5 in which the variable loading of the dielectric material along the helix portion compensates for the variations in wave phase velocity therealong which are due to the variable pitch, and maintain substantially constant wave phase velocity along the length of the helix portion.

7. A device according to claim 1 in which the means for counteracting the effect of variations in pitch of the said helix portion upon the uniformity of phase velocity comprises a second helix portion coupled to the said helix portion having predetermined variations in pitch along its length.

8. A device according to claim 7 in which variations in the coupling between the two helix portions along their lengths compensate for the variations in wave phase velocity along the length of the first said helix portion which are due to variable pitch, and maintains constant wave phase velocity along the length of the first said helix portion.

9. A device according to claim 7 in which said second helix portion has predetermined variations in pitch along its length.

10. A device according to claim 7 in which said second helix portion has predetermined variations in diameter along its length.

11. A device according to claim 7 in which said second helix portion has predetermined variations in pitch and diameter along its length.

12. In a traveling wave tube utilizing a wave transmission circuit for propagating electromagnetic waves in field coupling relation with an electron stream, the combination including a transmission circuit comprising a helix portion having predetermined variations in pitch along its length in the region of said field coupling relation, and means coupled to said helix portion for compensating for the variations in wave phase velocity therealong which result from the variations in pitch, said means comprising a member of dielectric material dimensioned and coupled in such a way to the helix portion that the wave phase velocity remains substantially constant, therealong.

13. In a traveling wave tube utilizing a wave transmission circuit for propagating electromagnetic waves in field coupling relation with an electron stream, the combination including a transmission circuit comprising a first helix having a first portion of uniform pitch, a second intermediate portion of varying pitch, and a third portion of uniform pitch, and means coupled to said second intermediate helix portion for compensating for the variations in wave phase velocity therealong which result from the variable pitch, said means including a second helix coupled to said first helix with a first portion of uniform pitch, a second intermediate portion of varying pitch, and a third portion of uniform pitch, each of said portions of said second helix being in coupling relation with the respective portions of said first helix.

14. A device according to claim 13 in which the variations in pitch of the intermediate portions of said first and second helices are substantially uniform with length therealong.

15. A device according to claim 13 in which the pitch of the intermediate portions of said first and second helices increases in one direction therealong in one part of the length and in the opposite direction therealong in another part of the length.

16. A device according to claim 13 in which the variations in pitch along the intermediate portion of said first helix is substantially uniform with length therealong and the intermediate portion of said second helix has predetermined variations in pitch and diameter therealong.

References Cited in the file of this patent

UNITED STATES PATENTS

2,489,082	De Forest	Nov. 22, 1949
2,541,843	Tiley	Feb. 13, 1951
2,630,544	Tiley	Mar. 3, 1953
2,641,731	Lines	June 9, 1953
2,727,179	Lally et al.	Dec. 13, 1955
2,730,648	Lerbs	Jan. 10, 1956
2,773,213	Dodds	Dec. 4, 1956
2,784,339	Lindenblad	Mar. 5, 1957
2,807,744	Lerbs	Sept. 24, 1957
2,825,841	Convert	Mar. 4, 1958
2,851,630	Birdsall	Sept. 9, 1958
2,888,596	Rudenberg	May 26, 1959