

May 31, 1960

J. S. COOK
COUPLING ARRANGEMENTS

2,939,092

Filed Oct. 29, 1954

2 Sheets-Sheet 1

FIG. 1

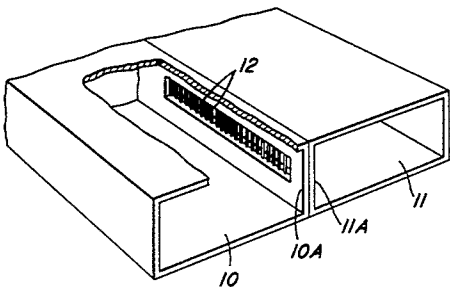


FIG. 2

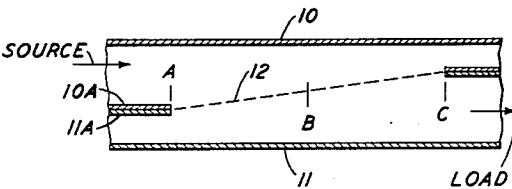


FIG. 3

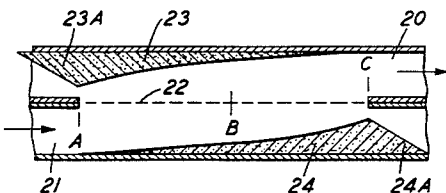


FIG. 4

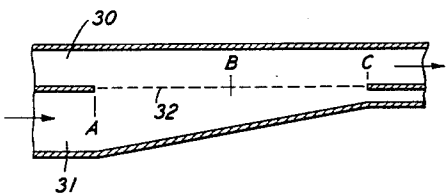


FIG. 5

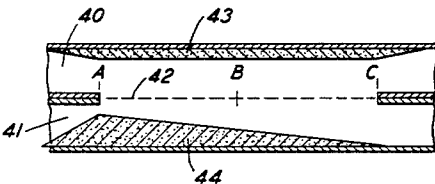
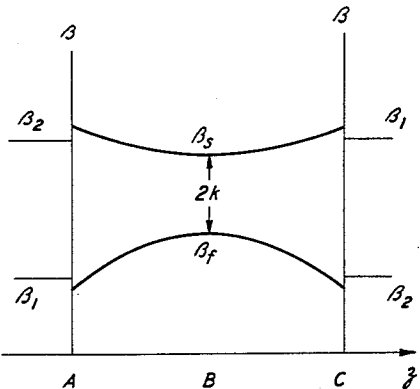


FIG. 6



INVENTOR
J. S. COOK

BY
Arthur J. Torsiglian
ATTORNEY

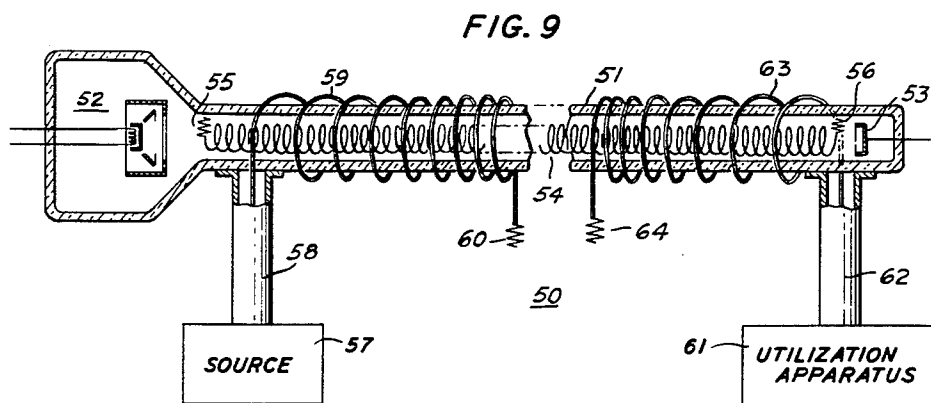
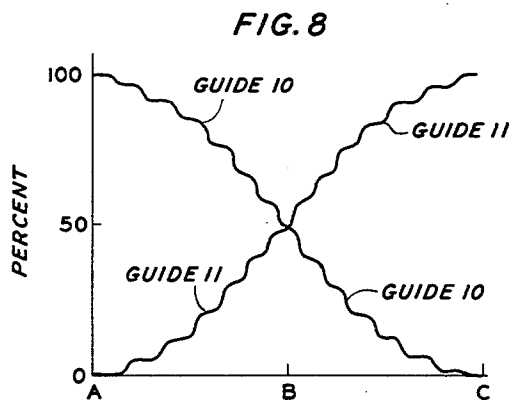
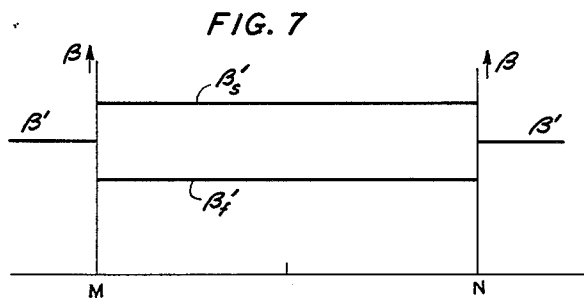
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2 Sheets-Sheet 2



INVENTOR
J. S. COOK
BY
Arthur J. Torrigliani
ATTORNEY

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2,939,092

COUPLING ARRANGEMENTS

John S. Cook, New Providence, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

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10 Claims. (Cl. 333—10)

This invention relates to coupled transmission lines and more particularly relates to arrangements for coupling in a directional manner a pair of transmission lines.

Directional couplers are known in the radio frequency transmission art as a means for transferring into a branch or auxiliary path for travel therealong in a preselected direction all or an appreciable portion of the wave energy continuing along in a given direction in a main path. From reciprocity considerations, such a coupler wave energy in a pair of paths may be combined for travel along a single path in a selected direction.

However, it has been characteristic of directional couplers of the prior art that they have all been frequency sensitive to a significant extent. Various configurations have been proposed hitherto which utilize special distributions of coupling between the main and auxiliary lines for operation over increased bandwidths, but these have not represented a complete solution to the problem. Accordingly, a directional coupler which is relatively insensitive to frequency over as wide a band of frequencies as is desired is of manifest utility for use in wide band transmission systems.

One object of the present invention is to increase the frequency response which can be achieved in a directional coupler.

The present invention is based on the discovery of a novel coupling principle which may be succinctly described here as normal mode tapering. The essence of such normal mode tapering involves a gradual change in the field distribution associated with one of the two normal modes in a coupler including a pair of lines such that initially the one normal mode corresponds to a distribution in which all the energy is in one line and eventually the same normal mode corresponds to a distribution in which all the energy is in the other line. The shift in the field distribution associated with the one normal mode is achieved by a change in the relative phase propagation constants of the two lines along the coupling region in a prescribed fashion. This principle will be described in more detail hereinafter.

It is characteristic of the coupled systems in accordance with the invention that the phase propagation characteristics of the two lines are made to vary with respect to one another over the coupling region. In particular, in embodiments where complete power transfer is sought between two coupled lines, the difference in phase propagation constants or characteristics of the two lines varies from a negative to a positive value over the coupling region. In such embodiments the crossover point of equal phase propagation characteristics corresponds to the point of equal division of the power between the two guides. In some embodiments to be described the phase propagation characteristic, which is familiarly designated as β , is made to vary along both lines over the coupling region and in opposite directions. In other embodiments to be described β remains constant in one line, and varies in the other line.

The invention will be better understood from the

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following more detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 shows in perspective view of a pair of hollow wave guides coupled to form a coupled system of the kind to which the principles of the invention are applicable;

Figs. 2, 3, 4 and 5 show in schematic form, as different embodiments of the invention, coupled lines in which along the coupling region the phase propagation parameters of the two lines taken separately varies in a prescribed manner;

Fig. 6 is a plot of the phase propagation parameters of a coupled line system in accordance with the invention;

Fig. 7 is a plot of the phase propagation parameters of a coupled system of the kind characteristic of the prior art;

Fig. 8 is a plot illustrating the exchange of energy between the two lines of systems of the kind shown in Figs. 2 through 5; and

Fig. 9 illustrates how the principles of the invention can be applied to the problem of coupling in and out of a traveling wave tube which utilizes a helix as its slow wave circuit.

Before discussing in detail specific embodiments, it will be helpful to discuss the general principles applicable in terms as non-mathematical as practical. It will be convenient to speak of the normal modes of a coupled line system. A normal mode as the term is used herein may be described simply as a mode for which a wave in the two coupled lines will propagate sinusoidally with distance and time and whose peak amplitude is independent of time and the coordinate in the direction of wave propagation. A system which comprises a pair of transmission lines which are tightly coupled so that a sizable fraction of the power in one can be transferred to the other has four normal mode solutions, two forward and two backward, of which only the former will be of concern here. In considering such a system the first and faster normal mode corresponds to the case where the wave excitation in the two guides is in phase, and the second and slower normal mode corresponds to the case where the wave excitation in the two guides is out of phase. Any excitation can be viewed as a combination of such two modes. It is characteristic of these two normal modes that in the cases of principal interest they have a different phase velocity and so, if both present, can interfere to give standing waves. The various directional couplers of the prior art generally have utilized this interference property to achieve directional selectivity. As such, they ordinarily have involved coupling regions whose length was a function of a quarter of the best wavelength. As a result of this dependence on an interference phenomenon, it is characteristic of this type of directional coupling that it is frequency sensitive. However, it is characteristic of embodiments in accordance with the invention that they do not depend on such an interference phenomenon and so can be relatively insensitive to frequency.

It is found typical of two coupled transmission lines in which the coupling and the difference in phase propagation constants of the two lines are uniform with distance over the coupling region that if one normal mode is started propagating along the line substantially none of its energy will be transferred to the other mode. Accordingly, if only a single normal mode were excited in such a system this normal mode would propagate without change, and directivity by interference could not be achieved. However, the field distributions associated with this normal mode would remain constant along the coupling region and no normal mode tapering would be possible. On the other hand, it is found that if either the difference of the phase propagation parameters or the coupling

varies along the coupling region, there will be a transfer of energy between normal modes. Coupling which results in such a transfer will be termed hyper-coupling. Inasmuch as in the practice of the invention it is important to minimize such energy exchange between modes, but characteristic to have a variation in the difference in the phase propagation parameters of the two lines, this variation is made gradual and the hyper-coupling weak. Some such variation in the difference in phase propagation constants is necessary for normal mode tapering in accordance with the invention whereby the field distribution associated with one normal mode varies from an initial condition in which all the wave energy is in one line to an end condition in which all the wave energy is in the other line.

It will now be convenient to discuss with particular reference to the drawing specific embodiments of the invention.

Fig. 1 illustrates in perspective view a coupled system comprising a pair of hollow wave guides of rectangular cross section which have contiguous or common narrow side walls 10A, 11A. The two wave guides are coupled to one another by a coupling aperture 12 which extends through side walls 10A and 11A. In practice this coupling aperture may be either a series of coupling slots extending therealong or an elongated slot with a grid of wires subdividing it as shown. The region coextensive with the coupling aperture will be termed the coupling or coupled region of the two guides.

Fig. 2 is a schematic representation of a coupled system of hollow wave guides in accordance with the invention in which the phase velocity in each of the two guides is varied by changes in its transverse dimension. The view depicted corresponds essentially to a top view with the top walls removed. The system shown provides a complete transfer of power between the two guides although for most wave guide applications power division other than a complete transfer is of primary interest. The two wave guides 10 and 11 are coupled together in the manner shown in Fig. 1 by way of a coupling aperture 12 shown here as the broken portion of the line representing the contiguous side walls 10A and 11A. In accordance with the principles of the invention, the phase velocity characteristics and hence the phase propagation characteristics of the two guides are made appreciably different from one another at point A the start of the coupling region. In particular, it is found that in the case of uniform coupling over the coupling region it is advantageous from the standpoint of improved directivity to have the phase velocity characteristics as different as feasible at A. In this embodiment the difference in phase velocity characteristics is achieved by different transverse dimensions for the two guides. As shown, at point A the transverse dimension of guide 10 is considerably wider than that of guide 11, resulting there in a lower phase velocity. The phase velocities of the two guides are tapered in opposite directions by appropriate changes in the transverse dimensions of the guides with progress along the coupling region from point A, and at an intermediate point B along the coupling region the phase velocities are equal. As shown, at point B the transverse dimensions of the two guides are equal. Point B corresponds to the 3 decibel power division point, i.e., at this point the power is equally divided between the two guides. A 3 decibel coupler can be conveniently had merely by discontinuing the coupling between the two lines at this point. Similarly, by discontinuing the coupling at other intermediate points, a corresponding intermediate power division can be realized. However, as shown, the coupling region extends therepast and the phase velocities continue to change in the same way with further progress along the coupling region so that at the end point C they are widely dissimilar in a sense opposite to that at point A. As at the starting point A, it is advantageous from a standpoint of direc-

tivity to have the phase velocity difference at point C as large as feasible. In this embodiment, the difference in phase propagation parameters will vary along the coupling region in the manner determined by the linear variation in the transverse dimensions of the two guides. In practice, it may be advantageous to employ different forms of variation of this difference. In particular, it appears preferable in the case of uniform coupling to employ a variation in the difference of phase propagation characteristics along the length of the coupling region which corresponds to a cotangent function of an argument between 0 and π radians at the center frequency of the band of operation.

As indicated above it is important to avoid too sharp changes in the variations which might give rise to hyper-coupling. As a result, for complete power transfers over a broad band of frequencies, it is found important to have the coupling region quite long, at least several wavelengths of the lowest frequency to be coupled.

It is found that the desired coupling can be achieved more readily if the coupling coefficient is varied in an appropriate manner at the same time as the difference in phase propagation parameters of the two guides is varied. In particular, it is found that the parameter of interest over the coupling region for normal mode tapering is

$$\frac{dH}{dz}$$

where H is the hyper-coupling parameter and

$$H = \left[\frac{\beta_2(z) - \beta_1(z)}{k(z)} \right]$$

where $\beta_1(z)$ and $\beta_2(z)$ are the phase propagation characteristics of the two guides over the coupling region in the absence of coupling as a function of the distance z along the coupling region, and $k(z)$ is the mutual and self-coupling coefficient between the two guides. In a co-pending application Serial No. 465,579, filed October 29, 1954 by A. G. Fox, now United States Patent 2,834,944, issued May 13, 1958, there are described coupling systems of this kind which utilize both variations in the coupling and in the difference of phase propagation characteristics.

In the system of Fig. 2, guide 10 is shown excited to produce an output excitation in the guide 11. Alternatively, guide 11 may be excited to provide an output excitation in guide 10. Moreover, from reciprocity considerations either guide may be excited for propagation in either direction.

The manner in which the normal modes are excited can best be described with reference to the plots of Fig. 6. In Fig. 6 there is plotted against distance along the coupling region the phase propagation characteristics of the two forward normal modes associated with a pair of guides coupled as shown in Fig. 2. There is being omitted the lengthy mathematical analysis leading to these results. Points A, B and C along the abscissa correspond to points A, B and C of the coupling region of the system shown in Fig. 2. The phase propagation characteristics along the coupling region can be shown to vary as depicted, the fast normal mode having a phase propagation characteristic β_f which reaches a maximum at B, the slow mode having a phase propagation characteristic β_s which reaches a minimum at B. At B, the difference between the parameters β_f and β_s corresponds to twice the coupling coefficient k which is a constant in the case under discussion.

It is found characteristic that at A the fast normal mode has a phase propagation characteristic β_f which nearly matches the phase propagation constant β_1 of the wave guide 11 with the faster phase velocity while the slow normal mode has a characteristic β_s which nearly matches the phase propagation constant β_2 of wave guide 10. In the plot, to the left of A there are plotted the phase propagation constants of the two guides to the

left of the start of the coupling region. The degree of mismatch is related both to the coupling and the difference in phase propagation constants of the two guides at A. In arrangements which employ uniform coupling, the larger the difference in phase propagation constants of the two lines the smaller is this mismatch. In arrangements which use both variations in coupling and in this difference, the mismatch may be eliminated.

It is further found characteristic in the case here described that at C the parameters β_t and β_s have values nearly equal to those of wave guide 10 with the fast phase velocity and wave guide 11 with the slow phase velocity, respectively. This corresponds to a shift in the matched relationship. The parameters β_t and β_s are matched to those of different wave guides at the two ends of the coupling region. This is consistent with the shift in field distribution between the two guides resulting from the normal mode tapering.

For the sake of simplicity guide 10 has been assumed to have a phase propagation constant at A equal to that of guide 11 at C and vice versa. Of importance is the fact that along the entire coupling region the two normal modes have different values. This is achieved particularly by having the propagation constants of the two guides very different at the boundaries of the coupling region. Hereinafter, with respect to Fig. 7 there is compared the phase propagation characteristics of a directional coupler of the kind which employs wave guides of substantially equal propagation constants at the boundaries of the coupling region.

Still with reference to Fig. 6, in operation when a wave is launched in only one of the two guides at point A, which of the two normal modes is excited in the coupling region is determined by which of the two guides is excited. If guide 11 is excited initially corresponding to excitation of the faster mode of the two uncoupled lines, the fast normal mode of the coupled system is excited preferentially because of the matched relationship in propagation constants therebetween. Alternatively, initial excitation of guide 10 excites the slow normal mode of the coupled system. To the extent of the degree of mismatch, the other normal mode is excited. At B, the power in the two guides will either be in-phase or out-of-phase, depending on which of the two normal modes is excited in the coupling regions. It is characteristic of a coupled system of this kind that when only one of the two guides is initially excited, because of the matched relationships plotted in the phase propagation parameters, only one normal mode is launched to an appreciable extent at the start of the coupling region. As a consequence, if the hypercoupling between the two normal modes is kept small along the coupling region the other normal mode remains substantially unexcited.

However, it is found that there is a transfer in energy between the two guides within the one mode. In particular, the transfer has the form shown in Fig. 8 where the percentage of power in each of the two guides is plotted against distance along the coupling region. The case depicted represents one in which the power was launched initially in guide 11. It is noted that there are ripples in the power characteristics of each guide. Such ripples result from the presence of a small amount of the undesired other normal mode resulting from the mismatch at the boundaries. By reducing this mismatch, the amplitude of the ripple can be reduced. Moreover, although there is not a complete transfer of power in the case of uniform coupling, the transfer approaches unity asymptotically so that for a sufficiently long coupling region the transfer is complete for all practical purposes. If the coupling is also varied, complete transfers of power are possible. It will generally be desirable to terminate the different ends of the wave guides in their characteristic impedances to minimize reflections.

Alternatively, by way of comparison there is shown in Fig. 7 a plot of the same form as that of Fig. 6 for direc-

tional couplers of the kind characteristic of the prior art in which the two guides uncoupled have the same phase propagation constants over the coupling region. In this plot, the region between M and N on the abscissa corresponds to the coupling region which after coupling is characterized by slow and fast forward normal modes of different propagation constants β'_s and β'_t , respectively. However, in regions before and beyond the coupling region the two guides have substantially the same propagation constant β' which has a value intermediate between that of β'_t and β'_s . Consequently, even though only one of the two guides is excited initially, because both the fast and the slow forward normal modes characteristic of the coupling region are equally mismatched to the propagation constant β' , a degeneracy exists at the start of the coupling region and both normal modes will be excited to approximately the same extent. Because such normal modes have different phase propagation parameters, interference therebetween results, and although such interference can be used to achieve directional coupling, such coupling is inherently frequency sensitive.

Various modifications are possible in the basic embodiment shown in Fig. 2. First it is possible to achieve the desired variation in $\beta(z)$ along the two lines without change in the physical dimensions of the wave guides by insertion of elements which vary either the dielectric constant or permeability of the wave guide medium. In the coupled system shown in Fig. 3 along the coupling region 22 there is incorporated in the guides 20, 21 inserts 23 and 24, respectively, to achieve this purpose. At A, the dielectric insert member 23 fills a considerable portion of guide 20 while the dielectric insert member 24 fills a smaller portion of the guide 21, whereby the value of the phase propagation parameter will be there larger in guide 20. At B, the dielectric inserts fill equal portions of the two guides, and at C the guide 21 is filled more by its insert member 24. The dielectric inserts are tapered along the coupling region to give a desired variation in relative phase propagation characteristics. A taper which results substantially in a cotangent function in the hypercoupling parameter H along the coupling region, as described above, is often advantageous. Various other distributions are also feasible. In practice it may be useful to include beyond the coupling region tapered extension portions 23A and 24A to the corresponding insert members to avoid abrupt discontinuities in the guides which may be disturbing. In this embodiment, too, the crossover point B corresponds to the 3 decibel point and by discontinuing the coupling there, a 3 decibel coupler results. Moreover, again either wave guide may be excited at either end for propagation in either direction although in general losses may be minimized by having the region of high wave energy level correspond to the regions of least dielectric insert, as is the case for excitation in the manner shown. Moreover, alternatively the insert members 23 and 24 may be of a material of high permeability, such as of ferrite, to achieve the desired variation in propagation constant.

Although in the two embodiments described above, the phase propagation characteristics of each of the two lines is varied along the coupling region, it is sufficient to vary the phase propagation characteristic of only one of the two lines, since it is the change in difference that is of primary significance. In Fig. 4, the guide 30 is of uniform cross section, and, accordingly, would have a uniform phase propagation constant along the coupling region 32 in the absence of coupling. Guide 31, on the other hand, has a transverse dimension which varies from a width wider than that of guide 30 at A to a width narrower than that of guide 30 at C. B is again used to designate the crossover point. As a result, the difference in the phase propagation characteristics changes sign on opposite sides of point B along the coupling region and increases in absolute value with increasing separation from B.

In Fig. 5 there is shown another embodiment of a coupled system in which the propagation constant of one line is varied over the coupling region while that of the other line is kept constant. In this case, the desired variation is achieved by a tapered insert member 44 in guide 41 either of dielectric or permeable material and a uniform insert member 43 in guide 40. To minimize reflections, these insert members are tapered at their ends beyond the coupling region 42 to avoid sharp discontinuities in the guides. At point B, the insert members 43 and 44 fill equal portions of the two guides.

In the embodiments described, the techniques used for achieving variations in the phase propagation characteristics of the two lines will result in accompanying variations in the characteristic impedances of the two guides. In some applications, this may be undesirable. Such variations in the characteristic impedances can be avoided. For example, in the case where the transverse dimension of a guide is varied to achieve a change in phase propagation characteristic, a compensating change in the height of the wave guide may be made to keep the characteristic impedance substantially constant over the coupling region. Alternatively, by the concurrent use of both dielectric and permeable insert members, the phase propagation constant of a guide may be varied without affecting substantially its characteristic impedance. This is possible because although the phase propagation constant of a wave guide varies in the same way with changes in either the dielectric constant or permeability of the bounded medium, its characteristic impedance varies in opposite directions for changes in the dielectric constant and permeability of the bounded medium.

Although in each of the embodiments described, the difference in phase propagation constants is achieved in a continuously tapering characteristic it is obvious that an analogous effect can be achieved by a series of discrete step variations.

Moreover, although the embodiments described above have related specifically to a coupled system comprising a pair of hollow wave guides, the principles can be extended to coupled systems comprising other forms of transmission lines.

In particular, the invention has special application to a coupled system comprising a pair of helical conductors. Helical conductors are assuming great importance as transmission lines in the field of traveling wave tubes wherein in one important form a helical conductor serves as an interaction circuit for propagating a slow electromagnetic wave past which is projected an electron beam. One of the problems characteristic of the use of a helical conductor in this way has been the difficulty in making wide band reflectionless connections thereto for coupling in the input signal and coupling out the output signal. In Fig. 9 there is shown a traveling wave tube embodying the principles of the invention.

In the traveling wave tube 50 shown in Fig. 9, an evacuated envelope 51, for example, of glass or quartz, houses the various tube components. At opposite ends of the tube, an electron source, shown schematically as the cathode 52, and the target electrode 53 define a path of electron flow therebetween. Disposed coaxially surrounding the path of electron flow is a helical conductor 54 which serves as the wave interaction circuit. The two ends of the helical conductor preferably are terminated to be substantially reflectionless, shown schematically by terminating impedances 55 and 56. For simplicity of manufacture, the helix 54 is wound of a uniform pitch. By suitable lead-in connections (not shown) a D.-C. potential is applied to the helix 54 which accelerates the electron flow therepast to a velocity substantially that of the axial velocity of the electric field of the wave propagating thereon, in the manner usual in traveling wave tube operation. It is usually desirable to make some pro-

vision (not shown here) for focusing the electron beam in its path of flow past the helix 54. In accordance with the invention, input wave energy is applied from an input wave source 57 to the upstream or cathode end of the interaction circuit by an input line 58 which comprises a coaxial conductor. For effecting a transfer of wave energy, the inner conductor of the coaxial line is provided with an extension 59 which is wound about the tube envelope in coupled relation with the upstream end of helix 54. The extension 59 which is a wire conductor is wound coaxially around the outside of the tube envelope over a region coextensive with the upstream end of the helix 54. The direction or sense of winding of the outer helix 59 is advantageously in a direction opposite to that of the inner helix 54 for enhanced coupling therebetween. In accordance with the principles of the invention, by variations in pitch the phase propagation characteristic of the outer helix 59 is gradually decreased from a value considerably larger to one considerably smaller than that of the inner helix 54 over the coupling region whereby the input wave is transferred completely from the outer helix to the inner helix for propagation therealong for interaction with the electron flow. The end of the outer helix is terminated in its characteristic impedance, shown schematically by impedance 60.

At the output or downstream end of the inner helix 54, the wave energy is abstracted therefrom for use by utilization apparatus 61 by a similar arrangement comprising a coaxial line 62 whose inner conductor includes an extension 63 which is formed into a helical conductor coaxially surrounding the envelope over a region coextensive with the downstream end of the inner helix. The outer helix 63, too, has a pitch variation which results in a phase propagation characteristic which varies from a value considerably larger to one considerably smaller than that of the inner helix over the coupling region and is terminated in its characteristic impedance shown schematically as impedance 64.

It is, of course, evident from what has been said above that the pitch of either of outer helices 59 and 63 alternatively might have varied to provide a phase propagation characteristic which changes from a value smaller to a value larger than that of the inner helix 54. Moreover, the pitch of the inner helix instead of being uniform may be varied so long as there is achieved the desired variation in the phase propagation characteristics of the inner and outer helices over the coupling region.

Moreover, it is to be noted that at the crossover point where the inner and outer helices have the same phase propagation constant substantially equal amounts of energy are in the two helices. Traveling wave tubes which utilize as the interaction circuit a pair of interwound helices to which connections are made in accordance with principles of the present invention are described in copending application Serial No. 465,580, filed October 29, 1954 by C. F. Quate, now, United States Patent 2,823,333, issued February 11, 1958.

It is to be understood that the specific embodiments described are merely illustrative of the general principles of the invention. Various modifications may be devised by one skilled in the art without departing from the spirit and scope of the present invention. Moreover, the principles of the invention may be incorporated in the various devices of the art which involve a directional transfer of power between a pair of separate lines, for example, a circulator.

What is claimed is:

1. A coupled line system comprising first and second hollow rectangular wave guides which are in field coupling relation with one another over a coupling region and characterized in that the width of at least one of the two wave guides varies along the coupling region whereby the difference in phase propagation characteristics of the two guides varies therealong, the phase propagation characteristics of the guides being different at each end of

the coupling region, the differences being of opposite sign.

2. A coupled line system comprising first and second hollow rectangular wave guides in field coupling relation with one another over a coupling region and dielectric means in at least one of said wave guides extending along the coupling region for varying the difference in phase propagation constants of the two lines along the coupling region, the phase propagation characteristics of the guides being different at each end of the coupling region, the differences being of opposite sign.

3. A coupled line system comprising first and second hollow rectangular wave guides in field coupling relation with one another over a coupling region and permeable material in at least one of said wave guides extending along the coupling region for varying the difference in phase propagation constants of the two lines along the coupling region, the phase propagation characteristics of the guides being different at each end of the coupling region, the differences being of opposite sign.

4. A coupled line system comprising first and second transmission lines in field coupling relation with one another and characterized in that at one end of the coupling region the characteristic phase propagation constant of the two lines is appreciably different, and the hyper-coupling parameter varies with distance along the coupling region substantially as a cotangent function.

5. An arrangement for effecting power transfer between a pair of coupled transmission lines comprising first and second transmission lines in field coupling relation with one another over a region of uniform coupling and characterized in that the hyper-coupling parameter varies along the coupling region substantially as a cotangent function.

6. A coupled line system comprising first and second transmission lines in field coupling relation with one another over a coupling region and characterized in that the difference in the characteristic phase propagation constants of the two lines decreases without change in sign from a significant value at one end to substantially 0 at the other end, said coupling region being further characterized by being of uniform coupling and the hypercoupling parameter varies substantially as a cotangent function between

$$0 \text{ and } \frac{\pi}{2}$$

along said region.

7. A coupled line system comprising first and second transmission lines in field coupling relation with one another over a coupling region and characterized in that at one end of the coupling region the characteristic phase propagation constants of the two lines are different, at least one of said lines having a changing characteristic phase propagation constant in the coupling region such that at an intermediate point of said region the characteristic phase propagation constants of the two lines are equal and at the other end of the coupling region they are different, the difference being of opposite sign

from the difference of the characteristic phase propagation constants at said one end.

8. An arrangement for effecting a substantially complete transfer of energy from one transmission line to another transmission line comprising first and second transmission lines in field coupling relation with one another over a coupling region which is long relative to the wavelength of the wave energy to be transferred and characterized in that at one end of the coupling region the characteristic phase propagation constants of the two lines are different, at least one of said lines having a changing phase propagation constant in the coupling region such that at an intermediate point of said region the characteristic phase propagation constants of the two lines are equal and at the other end of the coupling region they are different, the difference being of opposite sign from the difference of the characteristic phase propagation constants at said one end.

9. A coupled line system comprising first and second helices concentric with one another over a coupling region and characterized in that at one end of the coupling region the characteristic phase propagation constants of the two helices are different, at least one of said helices having a changing characteristic phase propagation constant in the coupling region such that at an intermediate point of said region the characteristic phase propagation constants of the two lines are equal and at the other end of the coupling region they are different, the difference being of opposite side from the difference of the characteristic phase propagation constants at said one end.

10. In a traveling wave tube, means forming a path of electron flow, an interaction circuit comprising a first helical conductor positioned along the path of flow for propagating an electromagnetic wave in field coupling relation therewith, and means in energy exchange relation with said interaction circuit comprising a second helical conductor positioned in field coupling relation with said first helical conductor over a coupling region and characterized in that at one end of the coupling region the phase propagation constants of the two helical conductors are different, at least one of said helical conductors having a changing phase propagation constant such that at an intermediate point of said region the characteristic phase propagation constants of the two lines are equal and at the other end of the coupling region they are different, the difference being of opposite side from the difference of the characteristic phase propagation constants at said one end.

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