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TRANSMISSION LINE COUPLING

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TRANSMISSION LINE COUPLING

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This invention relates to transmission lines and more particularly to directional couplers.

Directional couplers coupling transmission line systems are known and the theory of their operation is fairly well understood. For example, reference may be had to the article by H. J. Riblet on the "Mathematical Theory of Directional Couplers" in Proceedings of the I. R. E. for November, 1947, the article beginning at page 1307, and also to the volume on Technique of Microwave Measurements by Montgomery et al., Radiation Laboratory Series, volume 11, chapter 14. The type of directional coupler generally considered in these publications is one having a series of reactive coupling elements or a continuous reactive coupling (which may be considered as an infinite number of infinitely small couplings) such as the slot coupler between two waveguides. Directional couplers of this type in general are very broad banded devices. This is a continuing application of my application Serial No. 787,233, filed November 20, 1947.

It is an object of the present invention to provide a directional coupler having band pass characteristics.

It is another object of the invention to devise a novel directional coupler.

Another object of the invention is to provide a directional coupler particularly well suited for use with amplifiers and particularly for travelling wave tubes.

These and other objects, advantages, and novel features of the invention will be more apparent from the following description and the accompanying drawing in which similar reference characters are employed for similar elements and in which:

Fig. 1 is a schematic representation partially in longitudinal cross-section view of a first embodiment of the invention used in conjunction with a travelling wave tube;

Fig. 2 is a graph which aids in understanding the band pass effect secured in accordance with the invention; and

Fig. 3 is a schematic representation partially in longitudinal cross-sectional view of another embodiment of the invention used in conjunction with a travelling wave tube.

In accordance with the invention, I provide a directional coupler comprising a pair of transmission lines having a continuous reactive coupling longitudinally thereof, the length of coupling being that to provide substantially complete transfer of energy at the operating frequency, the two transmission lines having different phase

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velocities at other frequencies and equal phase velocities at the operating frequency. When the phase velocities are unequal, the transfer of energy is reduced. Particularly for use with travelling wave amplifiers, I prefer to employ transmission lines utilizing mutually coupled helical conductor elements wherein one of the helical elements may continue into the travelling wave tube so that the tube electron gun may direct a beam of electrons axially through or around the helical element. Because of the band pass effect, the directional coupler of the invention is especially advantageous in connection with travelling wave tubes. The band pass effect tends to prevent oscillations at undesired frequencies and thus permits use of a travelling wave tube of very high gain without such troublesome oscillations occurring, as will become more fully apparent hereinafter. It will be understood that the term "transmission line" includes wave guides as well as two-conductor transmission lines, or combinations thereof. Further, I prefer to employ absorptive terminations which, when used with other features of the invention, tend to prevent amplification of wave energy at undesired frequencies, and increases the band-passing effect of the coupler.

Referring now more particularly to Fig. 1, a travelling wave tube 10 comprises an envelope 12 and a helical conductor or coiled radio frequency transmission line 14 within the envelope 12 and having a longitudinal axis along which a beam of electrons is directed by a gun 16 toward a collector 18. The gun 16 directs a cylindrically shaped beam of electrons travelling with a velocity somewhat greater than the velocity of waves along the coil 14 in the band of frequencies to be amplified. With such a tube, radio frequency energy of low amplitude introduced to the line 14 may be amplified considerably at the output end near the collector 18. An amplification ranging up to a million or more in power may be obtained in a single tube. The tubes may operate at frequencies of the order of thousands of megacycles and handle band widths of tens of megacycles. Power gain may be as high as 10^{10} or 100 decibels. One form of this type of amplifier has been described in my patent application, Serial No. 787,232, filed November 20, 1947.

One of the serious difficulties in the design and operation of such a high gain travelling wave tube is that the gain is effective over an extremely broad band of frequencies. The tube sometimes sets up self-oscillations at frequencies where the proportion of energy feedback is equal

to or greater than the gain. One previously known method of preventing self-oscillation is to give the coiled line 14 inside the tube so much attenuation by a resistive coating or the like, that waves of any frequency reflected back from the output end to the input end are so greatly attenuated that oscillation is not possible. This expedient is effective to prevent the undesired oscillations by damping, but is open to the objection that the line attenuation tends to lower the gain of the tube at the desired frequency. Consequently, a tube having such a line with attenuating means sufficient to make it stable and free from self-oscillations has less total net gain and less gain per unit length than if such attenuation could be omitted or if no feedback due to reflections at the input and output ends could take place. I have found that the self-oscillations in a travelling wave tube may be overcome, or at least the probability of oscillation substantially reduced, by the arrangement of Fig. 1. In this arrangement the two ends of the amplifier coil are each terminated in high loss sections which cause low reflection of waves at both ends. For a considerable length around the input coil 20, which may be a continuation of or merge smoothly into the internal travelling wave tube coil 14, I provide a second coil 22 of larger diameter and may be of different pitch for reasons pointed out hereinafter, than coil 22 which preferably has a high loss impedance matching section at the end next to tube 10, as indicated by the resistive matched termination 23. Coils 22 and 20 have a common longitudinal axis. It will be apparent that this structure, is that of a directional coupler with a substantially continuous reactive coupling between transmission lines over the lengths of the lines. At the desired operating frequency, the coils 20 and 22 are designed by appropriate choice of pitch and other factors to have substantially the same phase velocity. The length of the coupled portions of the coils is made just that length which gives a substantially complete transfer of energy at the operating frequency. The energy may be fed in at the input end of coil 22 at the point 24 to be entirely transferred to the coil 20 in the course of its travel toward the output end of coil 22 where coil 22 terminates. At other frequencies, if the coils were to have the same rate of change of phase velocity with frequency, the coupling would still give substantial transfer of energy, the completeness of the transfer generally being less than 100% because of a somewhat incorrect length of coupling sections. However, I design the coils so that over the coupling length the rate of change of phase velocity with frequency is much greater in one of the coils than in the other. Thus the coils have substantially the same phase velocity and optimum length of mutual coupling at and immediately about the operating frequency only. At other frequencies, there is much less energy transference from one coil to the other.

An input transmission line 26 is coupled at the input end to coil 22 by a connection 24 to the inner conductor of coaxial line 26. Transmission line 20 at the end remote from travelling wave tube 10 extends beyond the coupled portions of lines 20 and 22 into a portion 28 having a resistive coating 30 or the like.

At the output end the travelling wave tube coil 14 is continued into an output coil 32 which in turn is coupled by a directional coupler arrangement similar to that at the input side of the

travelling wave tube 10 to a coil 34, except that it will be understood that the direction of travel of energy is from the inner to outer coil. Coil 34 is preferably terminated in a high loss impedance matching section 35 at its end next to tube 10 and at its other end is coupled to coaxial transmission line 36 by a connection 38 to the inner conductor thereof. Coil 32 is continued beyond the coupling in a portion 40 having a resistive coating 42 or the like. A suitably formed shield 43 surrounds the structure to complete these transmission lines.

In operation, energy at the operating frequency which is to be amplified is supplied to coaxial transmission line 26 thence to coil 22 and is transferred substantially completely to coil 20 as will be clear from the publications hereinbefore cited. The coil 20 then carries the energy into the travelling wave tube 10 where it is amplified and appears in the output coil 32. Energy at this frequency is again substantially completely transferred to coil 34 and thence to coaxial transmission line 36 which is the output line. However, consider now energy at other frequencies. Suppose that energy at some non-operating frequency enters transmission line 26. A substantial proportion of the non-operating frequency energy is not transferred to line 20 but is absorbed in the resistive termination 23 of line 22, next to tube 10, or is reflected back, some returning to the line 26 and some being absorbed in termination 28. Energy at the non-operating frequency originating in the tube and travelling back line 20 toward the input end similarly is not transferred completely to line 22 but much of it continues toward the portion 28. This portion is supplied with a resistive characteristic which substantially completely absorbs and dissipates the energy as heat. Many ways are known of imparting such a characteristic. For example, the coil portion 28 may be made of relatively high resistance magnetic material such as iron or Kovar, which is a very well known alloy closely matching the expansion of a particular kind of glass known as Corning glass #7052. Alternatively, or in conjunction therewith, the supporting element for line portion 28, which commonly may be made of glass, may be made semiconducting by heat treatment in vacuum or in hydrogen to remove some oxygen from the glass. Alternatively, or in addition, a glass surface separating the turns of the coil may be coated with a resistive film of lossy material such as carbon, or colloidal graphite. Of course, the terminating portions 23, 28, 35, and 42 are preferably matched to reduce reflections. The resistive characteristic of line portion 28 causes absorption of any portion of the energy travelling back along the line 20 at the undesired frequency which has not been transferred to line 22. In this fashion feedback at the undesired frequency is substantially reduced. It will be understood that because of the substantial difference in the rate of change of phase velocity along coils 20 and 22, that non-operating frequency waves can not readily be transferred from one to the other. Refer now to the output end, non-operating frequency energy cannot be transferred efficiently from coil 34 to coil 32 for the same reasons that non-operating energy cannot be transferred readily from coil 22 to coil 20. Similarly, non-operating frequency energy originating at the output end of travelling wave tube 10 and travelling down coil 32 is to a large degree absorbed in the portion 40, and if some is reflected a portion of that reflected is

absorbed in the termination 35. Although not shown in Fig. 1, conventional impedance matching means may be used between the coaxial lines and the coupling coils to give a good impedance match at the operating frequency.

Referring now to Fig. 2 there is illustrated the manner in which the phase velocity of coils of different diameter can be made to vary with wave length or frequency. Two coils of different diameter may have the number of turns per unit length so selected that the two coils have equal phase velocities, assuming that the velocities are measured parallel to the axis of the coil at a selected frequency. The coil with the smaller diameter will be given the greater number of turns per unit length. It will then be found that at frequencies different from the selected frequency the phase velocities become unequal. As illustrated in Fig. 2, the phase velocities may be made equal at a wave length of 6 centimeters (frequency 5000 megacycles) but the velocities will become progressively different at higher or lower frequencies. The graph of Fig. 2 shows the ratio of phase velocity v to the velocity of light, c , for a particular pair of coils plotted as a function of wave length in air in centimeters, and is illustrative of the type of variation in rate of change of phase velocity with frequency which may be secured by appropriate design. It is clear that there is only one wave length or frequency at which the phase velocities are equal, and at which the substantially complete transfer of energy mentioned in the above publications can occur. Thus a band pass effect is derived for the passage or transfer of energy from one of the coupled coils to the other. In general, the phase velocity of a transmission line having a coil as here illustrated, depends on the coil diameter, turns per inch, and size of coil wire, and the rate of change of phase velocity depends also on these parameters. The curve V_6 is for a coil of 0.4 cm. coil diameter with 6.66 turns per inch. The curve V_8 is for a coil of 0.8 cm. coil diameter with 3.1 turns per inch.

The rate of change of phase velocity with change of frequency can be made much greater than that indicated in Fig. 2 if the coils are periodically loaded with fixed capacities or, more broadly, by giving periodic variations to the inductance and/or capacity per unit length of line. In general, giving a periodicity to the line in this way gives it the characteristics of a high or low pass filter having a rapid change in phase velocity in the cut-off region. It is possible to give one line a high pass and one a low pass characteristic, and to place the operating frequency in the cut-off region of both while at the same time the phase velocities are matched at the operating frequency and the coupling length is correct for nearly 100% energy transfer at the operating frequency.

Referring now more particularly to Fig. 3, the travelling wave tube 10 is coupled to the coil 20 in the same manner as in Fig. 1. The coil 22 is coupled to the coil 20, however, in a somewhat different manner by being placed with its axis parallel to the axis of coil 20 and in close proximity to coil 20 so that there is a substantially continuous coupling of a sufficient axial length of the coils to give substantially complete energy transference from one coil to the other at the operating frequency. As before, the coils 20 and 22 have phase velocities which vary at a different rate with respect to frequency and therefore have only one frequency, the operating frequency, at which the phase velocities are equal. In the de-

vice of Fig. 3 a resistive terminating portion 28 is again provided at the end remote from travelling wave tube 10. A coaxial input waveguide 50 merges smoothly and gradually into a coil portion 52 which is continued into the portion 22. At the other end from that at which coils 52 and 22 merge, coil 22 is continued into a portion 54 which terminates the coil 22 in a highly resistive preferably impedance matching termination.

In the embodiment of Fig. 3, energy supplied to coaxial line 50 passes through the coil portion 52 into the portion 22 where it is coupled substantially into line 20 if at the operating frequency. If at a non-operating frequency, much of the energy continues along 22, because it will not be transferred fully in view of the band pass effect of the coupling, and the portion not transferred is substantially absorbed in the terminating coil portion 54. Non-operating frequency energy originating at tube 10, or reflected therefrom if some is transferred to coil 20 passes down the line 20 in the direction toward terminating portion 28, most of the energy again not being transferred to transmission line coil 22 but passing to the resistive termination 28 to be substantially absorbed. It will be obvious to those skilled in the art that other transmission lines than those having coils (for example hollow pipe waveguides) and having different rates of change of phase velocities with respect to frequency may be coupled to provide a band pass directional coupler by using the invention disclosed herein.

In practice, in order to obtain a more rapid diminution of energy transfer with departure of the wave frequency from the selected operating frequency, I may make the region of mutual coupling between the lines so long that the wave energy may transfer back and forth between a nearly complete transfer at the selected operating frequency. In this case the length of the coupling may of course become correct for maxima of energy transfer at other frequencies both above and below the selected frequency, but the energy transfer will be less than the maximum for the selected frequency because of the difference in phase velocities of the lines at the frequencies of secondary maxima.

It will be apparent that I have disclosed a new and novel directional coupler having a band pass effect and being particularly useful and having unusually desirable results when employed in conjunction with a travelling wave tube.

What I claim is:

1. A directional coupler comprising a pair of transmission lines each comprising a coil wound coaxially with the other about a longitudinal axis and coupled along an axial length of each at least a plurality of wavelengths at the operating frequency by being placed in close proximity to each other with said axes substantially parallel over said lengths, said lines over said lengths being so dimensioned and arranged as to have substantially the same phase velocities for electromagnetic energy at the operating frequency and to have phase velocities different from each other for electromagnetic energy at frequencies other than the operating frequency, whereby a band-pass effect is obtained in the coupling of energy from one said line to the other.

2. In combination with a travelling wave tube having a first transmission line having an input portion and an output portion, a directional coupler comprising second and third concentric transmission lines having a substantially continuous reactive coupling over a length thereof

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at least a plurality of wavelengths at the operating frequency to provide substantially complete transfer of electromagnetic energy at the operating frequency, said second and third lines being so dimensioned and arranged as to have substantially the same phase velocity for said energy at the operating frequency, the dimensioning and arrangement being such that each said second and third lines have a different rate of change of phase velocity with respect to frequency than the other, said second line being connected at one end portion thereof to said first line input portion.

3. In the combination claimed in claim 2, said second line having a resistive termination at the other end thereof.

4. In the combination claimed in claim 2, said second and third lines comprising coils each wound around a longitudinal axis, said coils being placed in close proximity to each other with said axes substantially parallel over said coupling length.

5. In the combination claimed in claim 4, said second and third line coils being coaxial over said length.

6. In the combination claimed in claim 2, said second and third lines comprising coils each wound around a longitudinal axis, said coils being placed in close proximity to each other with said axes spaced from and parallel to each other over said coupling length.

7. In the combination claimed in claim 2, said transmission lines each comprising a coil, the connection of said second line at said one end portion thereof to said first line input portion comprising a smooth continuation of said second line coil into said first line coil.

8. In combination with a travelling wave tube having a first transmission line having an input portion and an output portion; an input arrangement comprising second and third transmission lines each having a substantially continuous reactive coupling with the other over a length thereof at least a plurality of wavelengths at the operating frequency to provide substantially complete transfer of electromagnetic energy at the operating frequency, said second and third transmission lines each being so dimensioned and arranged as to have substantially the same phase

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velocity for said energy at the operating frequency and a rate of change of phase velocity with energy frequency different from that of the other, said second line being connected at one end portion thereof to said first line input portion; and an output arrangement comprising fourth and fifth transmission lines each having a substantially continuous reactive coupling with the other over a length thereof at least a plurality of wavelengths at the operating frequency to provide substantially complete transfer of electromagnetic energy at the operating frequency, said fourth and fifth transmission lines each being so dimensioned and arranged as to have substantially the same phase velocity for said energy at the operating frequency and a rate of change of phase velocity with energy frequency different from that of the other, said fourth line being connected at one end portion thereof to said first line output portion.

9. In the combination claimed in claim 8, said transmission lines each comprising a coil wound around a longitudinal axis, said second and third transmission line coils being coupled by being placed in close juxtaposition with the axes thereof substantially parallel over said length, said fourth and fifth transmission line coils being coupled to each other similar to the said coupling of said second and third transmission line coils to each other, the said connection between said second and first lines and that between said fourth and first lines comprising respectively a smooth continuation of said coil of said second line into that of said first line and that of said first line into that of said fourth line.

10. In the combination claimed in claim 9, the other end portion of said second line and the other end portion of said fourth line each comprising a resistive termination.

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REFERENCES CITED

The following references are of record in the file of this patent:

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Number	Name	Date
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