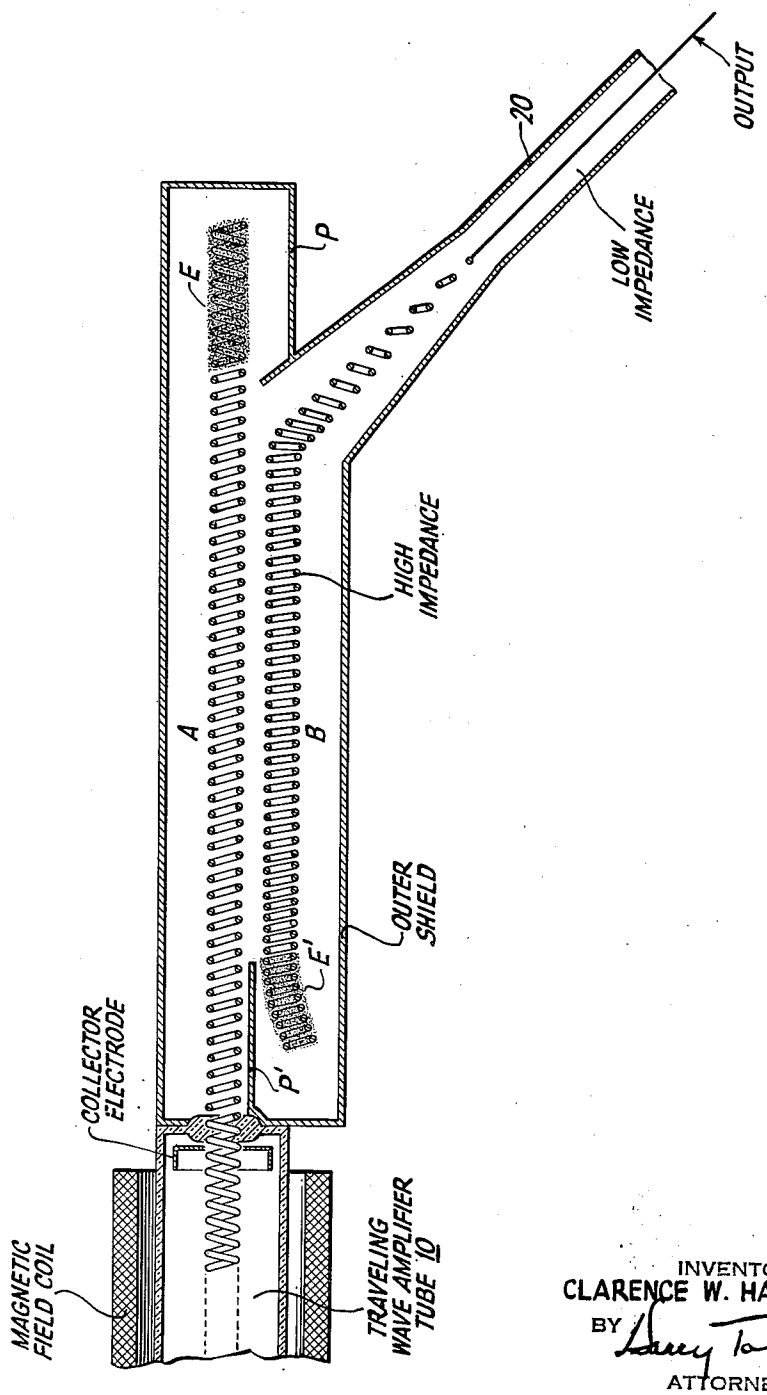
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HIGH-FREQUENCY ENERGY TRANSFER CIRCUIT

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HIGH-FREQUENCY ENERGY TRANSFER CIRCUIT

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This invention relates to a novel method of and means for transferring radio frequency power from one transmission line to another.

Among the objects of the invention are, in circuits for the transfer of radio frequency energy between a pair of coiled transmission lines: to avoid the occurrence of backward travelling waves; and to increase the frequency selectivity at which total radio frequency energy transfer from one line to the other occurs.

Briefly stated, the present invention comprises an energy transfer circuit for radio frequency power, in the form of two similar coiled transmission lines which are arranged parallel to but spaced from each other and coupled electrically for a distance chosen such that transfer of energy therebetween is substantially complete at a particular frequency. The two coiled lines are preferably though not necessarily similarly dimensioned in diameter and pitch. In order to assure complete energy transfer between the two coiled lines, their axial wave or phase velocities should be equal, but the characteristic impedance of the coiled lines need not be alike. The coils are properly spaced and unshielded from one another for a suitable distance to effect the desired degree of energy transfer therebetween, and preferably they are so terminated that waves transferred from one coil to the other travel in the last coil in the same direction as the waves in the first coil, with negligible backward traveling waves. The spacing between coils is adjusted to a correct value to cause a complete transfer of energy within those portions of the lengths of the coiled lines which are coupled together, and this may be achieved by trial while watching meter readings of the currents along the lines. The backward traveling waves are caused by reflections after the coupling is effected and these may be controlled to be very small or appreciable, as desired. One manner of reducing these reflected waves to prevent rereflection, forward again in the direction of the original waves, is to provide high attenuation ends for the coils, as for example, by coating the ends of the coils with a layer of colloidal graphite sold under the trade name Aquadag. However any other means for giving the ends of the lines a high attenuation may be used.

A more complete description of the invention follows. The foregoing and other objects, advantages, and novel features of the invention will be more fully apparent from this description when read in conjunction with a drawing whose single figure illustrates one embodiment of the invention given by way of example only.

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Referring to the drawing, there are shown two coiled transmission lines A and B correctly spaced from but coupled to each other by substantially continuous reactive coupling therebetween. Coiled line A may be considered as the primary coil since input waves are applied to one end thereof by any suitable source of very high frequency waves.

The source of input waves is here shown, by way of example only, as a growing wave (sometimes called a traveling wave) type tube 10, illustrated diagrammatically. The input end of coil A is shown as the continuation of the helix within the tube 10 and to which the electron stream is coupled. As is known, this growing wave tube is an evacuated electron discharge device which may comprise a helix arranged parallel and in energy transfer relation to a stream of electrons. The electrons travel down the stream at a velocity approximating but somewhat greater than the axial velocity of the waves traveling along the helix. Near the source of the electron stream within the tube, the electrons are bunched by input waves which deliver energy to the stream, while at points removed from the input end of the helix, the bunched electrons, representative of amplified waves, deliver energy to the helix. A magnetic field coil serves to focus the electron stream along or parallel to the longitudinal axis of the tube. For a general description of the operation of such growing wave tubes reference is herein made to Lindenblad Patent 2,300,052, granted October 27, 1942, and to my copending application Serial No. 787,232, filed November 20, 1947.

In order to prevent reflections of waves traveling axially along the length of primary coil A there is provided at end E of the coil A, a region of high wave attenuation, which may be obtained by applying a layer of Aquadag. Stated otherwise, the end E remote from the input end of the coil A is a lossy end which almost completely dissipates or absorbs power from the waves reaching the end.

Coiled line B may be considered as the secondary coil which by proper exposure and spacing from coil A obtains a substantially continuous reactive coupling for a complete transfer of energy of a selected frequency or band of frequencies from coil A, with a wave traveling along coil B in the same direction as the wave traveling along coil A. One end E' of coil B is coated with a layer of Aquadag or otherwise given high attenuation, in the same manner as end E of coil A, in order to provide a high attenuation termination and prevent wave reflections at this end. The other

end of coil B is tapered in diameter and pitch (decreasing diameter and increasing pitch) so as to gradually reduce the characteristic impedance of this end to a characteristic impedance of the order of 50 to 75 ohms while the characteristic impedance of coils A and B at their exposed portions may be as great as several hundred ohms or more.

In order to shield the lossy or high attenuation end E of the coiled line A from the adjacent portion of the line B, and to shield the lossy end E' of the coiled end B from the adjacent portion of line A, there are provided, metallic partitions P and P', respectively, which prevent useful energy of the waves traveling in a forward direction in the coiled lines A and B from getting into these lossy portions.

The magnitude of the current in coiled line A will be a maximum near the input end and gradually fall off to a minimum near the lossy end E. Similarly, the magnitude of the current in coiled line B will be a minimum near the lossy end E' and a maximum near the end coupled to the utilization circuit or coaxial output line 20. This condition will exist for correct spacing between coiled lines A and B for complete energy transfer therebetween.

Axial velocities of waves along both coiled lines (each taken alone) should be equal for complete energy transfer, although the characteristic impedances of both coiled lines need not be alike. The spacing and/or length of exposure between the two lines is adjusted to a correct value to cause a complete transfer of energy within those portions of the lengths of the coiled lines which are coupled together. This is effected by trial while watching meter readings of the currents along the lines, although, once correct relationships have been determined they may be duplicated in construction.

This complete energy transfer will take place at a particular optimum frequency. At frequencies far removed from this particular frequency, the net energy transferred from one coiled line A to the other B will not be complete. At frequencies much higher than the optimum for complete net transfer of energy, it will be found that the energy in the primary coiled line A first transfers itself completely to the secondary coiled line B but before the end of the coupling region is reached much of the energy of the transferred waves will be returned again to the primary line A. At frequencies much lower than the optimum, there will be incomplete transfer of energy; or putting it in other words, the coupling region will be too short for complete energy transfer. Thus there is frequency selectivity over a broad band of frequencies. This arrangement may be used to transfer nearly all the energy within a band of frequencies having a range of the order of less than 2 to 1.

When increased frequency selectivity is desired, the lines may be given different dimensions of diameter, pitch and dielectric constant of the support, resulting in different impedances and a different rate of change of phase velocities with frequency, provided the velocities still match at the desired range of frequencies. Then the velocities become unequal at other frequencies, which diminishes energy transfer at these other frequencies.

As a refinement, it may be advisable to have a tapered coupling between the two coiled lines A and B by having the coils slightly diverge from each other along their lengths, so as to minimize small reflections which may otherwise take place at the ends of the coupling regions.

The coupled regions of the two coiled lines A and B may be 15 wavelengths more or less at the mean operating frequency, the wavelength being measured along the coil, not at the velocity of light. Coiled lines A and B are shown mounted within an outer shielded metallic envelope to prevent wave energy transfer to and from nearby surfaces and objects.

The frequencies used in the transfer of energy from one coil to the other may range anywhere from 500 megacycles up to thousands of megacycles.

Although I have described the coupling as applied to the output end of a growing wave amplifier, it should be understood that the same arrangement may serve for coupling to the input end of the amplifier merely by reversing the direction of the waves through the system.

An advantage of this frequency selective energy transfer system is that the waves not transferred are to a very large degree absorbed in the lossy portions of the lines so that to and fro wave reflections cannot take place to any substantial degree at any frequency. In the growing wave amplifier application, this feature is very helpful in preventing uncontrolled oscillation of the amplifier of a kind usually referred to as parasitic oscillations.

What is claimed is:

1. The combination with a radio frequency energy transfer circuit comprising a coiled line a plurality of wavelengths long at the operating frequency of the waves adapted to travel thereover in an axial direction, a portion of said coiled line solely near one end being constructed and arranged to provide high attenuation for said waves passing over said line, of means for supplying high radio frequency waves to said coiled line at a location removed from said one end to travel in said direction toward the other end comprising a second coiled line coupled to said first with substantially continuous reactive coupling over a plurality of wavelengths at the operating frequency, and means remote from said one end abstracting high frequency waves from said first line.

2. The combination with an energy transfer circuit comprising a coiled line a plurality of wavelengths long at the frequency of the waves adapted to travel thereover in an axial direction, a coating of material on solely one end of said coiled line, said coating comprising a layer of a material which provides high attenuation for said waves, of means for supplying high frequency waves to said coiled line at a location removed from said one end, and means for abstracting high frequency waves from said line from another location removed from one end.

3. A coiled transmission line a plurality of wavelengths long at the mean operating frequency of the waves adapted to pass thereover, the turns of said line located solely near one end being constructed and arranged to provide high attenuation for said waves passing along said line in order to reduce wave reflections from said one end, the other end of said line being tapered in diameter and pitch for association with a utilization circuit.

4. A coiled transmission line a plurality of wavelengths long at the mean operating frequency of the waves adapted to pass thereover, a portion of said line solely near one end being coated with a material which provides high at-

tenuation for said waves traveling over said line to reduce reflections from said one end, the other end of said line decreasing gradually in diameter and increasing in pitch for reducing the terminal characteristic impedance of said line.

5. An energy transfer circuit between a source of high frequency waves and a utilization circuit, comprising a coiled transmission line a plurality of wavelengths long at the mean operating frequency of the waves adapted to pass over said line, one end of said line being coupled to said source and means coating said line solely near the other end with a material which provides a high attenuation for the waves reaching said last end, whereby wave reflections from said last end are minimized.

6. An energy transfer circuit for radio frequency power comprising a pair of spaced substantially parallelly arranged coiled transmission lines each a plurality of wavelengths long at the mean operating frequency and in energy coupling relation to each other solely by virtue of the spacing therebetween over a distance equal to a plurality of wavelengths long, said lines being so dimensioned and arranged that the axial velocities of the waves at a selected frequency along both lines are substantially equal, a portion of one coiled line located solely near one end and a portion of the other coiled line located solely near the opposite end being so constructed and arranged as to provide high attenuation for the waves traveling over the respective lines, the spacing and length of electrical exposure between said lines being so chosen as to effect a substantially complete transfer of energy between said coiled lines at said selected frequency.

7. An energy transfer circuit for radio frequency power comprising a primary coiled transmission line a plurality of wavelengths long at the mean operating frequency, a secondary coiled transmission line also a plurality of wavelengths long at the mean operating frequency and having a portion arranged substantially parallel and adjacent to a portion of said first line so as to be in energy coupling relation thereto solely by virtue of the spacing therebetween, the coupled portions of both lines being longer than several wavelengths at the mean operating frequency, means for supplying radio frequency power to one end of said primary coiled line, means for deriving radio frequency power from the opposite end of said secondary coiled line, the spacing between the coupled portions of said lines being so chosen as to effect a substantially complete transfer of energy between said coiled lines at said operating frequency, said lines being so dimensioned and arranged that the axial velocities of waves at said frequency traveling along both lines are substantially equal, said coiled lines have portions located solely at the other ends so constructed and arranged as to provide high attenuation for the waves traveling over the respective lines to reduce wave reflections.

8. An energy transfer circuit for radio frequency power comprising a primary coiled transmission line a plurality of wavelengths long at the mean operating frequency, a secondary coiled transmission line also a plurality of wavelengths long at the mean operating frequency and having a portion arranged substantially parallel and adjacent to a portion of said primary coiled line so as to be in energy coupling relation thereto solely by virtue of the spacing therebetween, the coupled portions of both lines being longer than several wavelengths at the mean operating frequency, means for supplying radio frequency power to one end of said primary coiled line, means for deriving radio frequency power from the opposite end of said secondary coiled line, the spacing between the coupled portions of said lines being so chosen as to effect a substantially complete transfer of energy between said coiled lines at said chosen frequency, said lines being so dimensioned and arranged that the axial velocities of waves at said frequency traveling along both lines are substantially equal, a coating of material at substantially solely the other ends of said lines, said coating material providing high attenuation for the waves traveling over the respective lines, to thereby minimize reflections from said last ends.

9. An energy transfer circuit for radio frequency power comprising a primary coiled transmission line a plurality of wavelengths long at the mean operating frequency, a secondary coiled transmission line also a plurality of wavelengths long at the mean operating frequency and having a portion arranged substantially parallel and adjacent to but spaced from a portion of said primary coiled line so as to be in energy coupling relation thereto solely by virtue of the spacing therebetween, the coupled portions of both lines being longer than several wavelengths at the mean operating frequency, means for supplying radio frequency power to one end of said primary coiled line, means for deriving radio frequency power from the opposite end of said secondary coiled line, the spacing between the coupled portions of said lines being so chosen as to effect a substantially complete transfer of energy between said coiled lines at said operating frequency, said lines being so dimensioned and arranged that the axial velocities of waves traveling along both lines are substantially equal, a coating of material at substantially solely the other ends of said lines, said coating material providing high attenuation for the waves traveling over the respective lines, to thereby minimize reflections from said last ends, and a shield between each of said last ends and the adjacent coiled line.

10. An energy transfer circuit for radio frequency power comprising a primary coiled transmission line a plurality of wavelengths long at the mean operating frequency, a secondary coiled transmission line also a plurality of wavelengths long at the mean operating frequency and having a portion spaced from and arranged substantially parallel and adjacent to a portion of said primary coiled line so as to be in energy coupling relation thereto solely by virtue of the spacing therebetween, the coupled portions of both lines being longer than several wavelengths at the mean operating frequency, means for supplying radio frequency power to one end of said primary coiled line, means for deriving radio frequency power from the opposite end of said secondary coiled line, said last end of said secondary coiled line being tapered in diameter and pitch to reduce the terminal characteristic impedance of said secondary coiled line, the spacing between the coupled portions of said lines being so chosen as to effect a substantially complete transfer of energy between said coiled lines at said operating frequency, said lines being so dimensioned and arranged that the axial velocities of waves traveling along both lines are sub-

stantially equal at said operating frequency, the other ends of said coiled lines being constructed to provide high attenuation for the waves traveling over the respective lines to reduce wave reflections.

11. The method of transferring energy between a pair of coiled transmission lines each a plurality of wavelengths long at the mean operating frequency, which includes paralleling said transmission lines in spaced relation for a distance at least equal to several wavelengths long so that they are in energy coupling relation to each other by virtue solely of the spacing therebetween, feeding one end of one of said lines with high frequency energy, abstracting energy from the opposite end of the other line, providing high attenuation terminations at the other ends of said coiled lines, dimensioning said lines such that the axial velocities of the waves along both coiled lines are equal, and so spacing said coiled lines from each other that there is a substantially complete transfer of energy from the line fed with high frequency energy to the line from which energy is abstracted at a desired band of frequencies.

12. The combination with an energy transfer circuit comprising a coiled line a plurality of wavelengths long at the frequency of the waves adapted to travel thereover in an axial direction, a portion of said coiled line solely near one end being constructed and arranged to provide high attenuation for said waves passing over said line, of means for supplying high frequency waves to said coiled line at a location removed from said one end, and means for inductively abstracting high frequency waves from a continuous portion of said line intermediate the ends thereof and which portion is a plurality of wavelengths long.

13. An energy transfer circuit for radio frequency power comprising a primary coiled transmission line a plurality of wavelengths long at the mean operating frequency, a secondary coiled transmission line also a plurality of wavelengths long at the mean operating frequency and having a portion arranged substantially parallel and adjacent to a portion of said primary line so as to be in energy coupling relation thereto solely by virtue of the spacing therebetween, the coupled portions of both lines being longer than several wavelengths at the mean operating frequency, means for supplying radio frequency power to one end of said primary coiled line, said means comprising an electron discharge device having as part thereof a coiled line extending therefrom and forming an integral part of said primary coiled line, means for deriving radio frequency power from the opposite end of said secondary coiled line, the spacing between the coupled portions of said lines being so chosen as to effect a substantially complete transfer of energy between said coiled lines at said operating frequency, said lines being so dimensioned and arranged that the axial velocities of waves traveling along both lines are substantially equal at said operating frequency, said coiled lines having portions located solely at the other ends so constructed and arranged as to provide high attenuation for the waves traveling over the respective lines to reduce wave reflections.

14. A frequency selective wave coupling system comprising two wave guiding systems of different dimensions having equal phase velocities at a selected operating frequency and substantially continuous mutual reactive coupling between the two systems of a degree and extending over a length at least a plurality of wavelengths at the operating frequency which results in substantially complete transfer of wave energy of the selected frequency entering the region of mutual coupling along one wave guiding system into the other wave guiding system while for frequencies departing from the selected operating frequencies the wave guiding systems have progressively different phase velocities due to the different dimensions whereby proportionately less wave energy is transferred from one system to the other.

15. Two wave guiding systems of different dimensions each terminated to prevent substantial wave reflections and having phase velocities which are alike at a selected frequency but which differ due to the different dimensions by an increasing ratio as the frequency departs from the selected frequency, the two wave guiding systems being mutually coupled together with a substantially continuous reactive coupling to a degree and over a selected length which results in substantially complete transfer of waves originally in one of the systems over to the other system only at or close to the selected operating frequency.

16. Two wave guiding systems of different dimensions each terminated to prevent substantial wave reflections and having phase velocities which are alike for a selected operating frequency but progressively different due to the differing dimensions for frequencies progressively further from the selected operating frequency, the two systems being substantially continuously and reactively coupled together over a length or distance such that waves of the selected frequency entering one of the systems are transferred by the mutual coupling back and forth from one system to the other finally appearing nearly completely in the other of the two systems while waves of frequencies different from the selected frequency are less completely transferred.

17. A directional coupler comprising a pair of transmission lines of different dimensions having a substantially continuous reactive coupling 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 transmission lines having substantially the same phase velocity for said energy at said operating frequency and each having a different rate of change of phase velocity with respect to frequency than the other due to different dimensions whereby the said energy is transferred with a band-pass effect.

18. A directional coupler comprising a pair of transmission lines each comprising a coil wound about a longitudinal axis and coupled by substantially continuous reactive coupling 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 having different dimensions and having substantially the same phase velocities for electromagnetic energy at the operating frequency and having phase velocities different from each other due to different dimensions for electromagnetic energy at frequencies other than the operating frequency the said lengths being that required for substantially complete energy transference from one

said line to the other at said operating frequency, whereby a band-pass effect is obtained in the coupling of energy from one said line to the other.

19. The combination with a traveling wave tube having a helical transmission line a plurality of wavelengths long at the frequency of the waves adapted to travel thereover in an axial direction, of another helical transmission line also a plurality of wavelengths long having a portion extending parallel to said first helical line and in energy transfer relation thereto by substantially continuous reactive coupling therebetween, said lines having different dimensions of diameter and a different rate of change of phase velocities with frequency over a range of frequencies departing from the operating range of frequencies.

20. A combination as defined in claim 19, characterized in this that said helical transmission lines have a different pitch.

21. The combination claimed in claim 18, said coil axes being parallel and spaced from each other.

22. The combination claimed in claim 18, said coil axes being parallel and spaced from each other, the said coils being positioned side-by-side.

23. A directional coupler arrangement comprising first and second transmission lines each having a coiled conductor portion at least a plurality of wavelengths at the operating frequency over the length of which there is a substantially continuous reactive coupling with that of the other, said lines having the same phase velocity over said length at the operating frequency, and each having on opposite sides of said coupling and removed therefrom one end portion decoupled from any portion of the other line except through the coupled line portions, means to apply electromagnetic energy to said one end portion of one line alone, the length of said

coupling being that required for substantially complete transfer of energy at the operating frequency incident from said one end portion to the other said line and travelling in one direction along said other line, whereby the energy transfer is complete at the operating frequency and less complete at other frequencies removed from the operating frequency, the said one end portion of the other said line being on the other side of said coupling, and means for withdrawing the transferred energy.

24. The arrangement claimed in claim 23, said transmission lines over said coupling portion having in at least one respect differing dimensions whereby the frequency selectivity of the transferred energy is increased.

25. The arrangement claimed in claim 23, one coil having differing dimensions from the other over said length.

26. The arrangement claimed in claim 23, each said coil being helical, the helix axis of one being parallel to that of the other over said length.

27. The arrangement claimed in claim 23, each said coiled portion having axes parallel to and spaced from the axis of the other over said length.

CLARENCE W. HANSELL.

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