

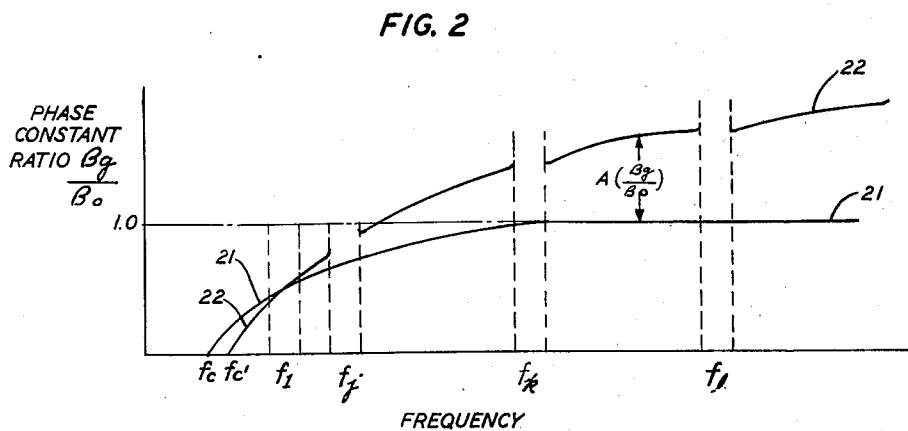
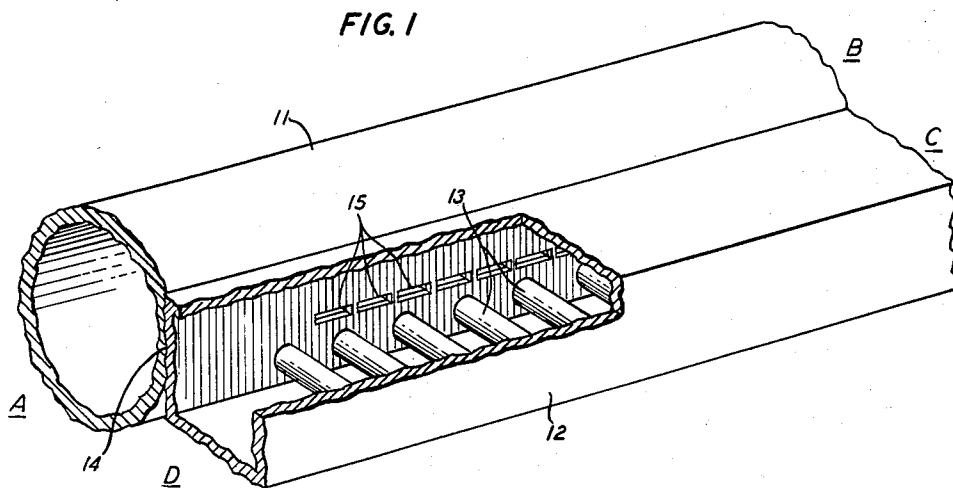
March 15, 1960

S. E. MILLER

2,929,032

FREQUENCY-SELECTIVE WAVE COUPLING SYSTEM

Filed Aug. 17, 1956



INVENTOR
S. E. MILLER
BY *Ray M. Porter, Jr.*

ATTORNEY

1

2,929,032

FREQUENCY-SELECTIVE WAVE COUPLING SYSTEM

Stewart E. Miller, Middletown, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Application August 17, 1956, Serial No. 604,739

9 Claims. (Cl. 333-73)

This invention relates to very high frequency or microwave electrical transmission systems and, more particularly, to frequency selective apparatus for segregating or branching wave energy of a given frequency or band of frequencies from one transmission system into another transmission system.

In my copending application, Serial No. 336,286, filed February 11, 1953, now United States Patent No. 2,879,484, granted March 24, 1959, there is disclosed a branching filter which in several aspects is similar to the structures of the directional coupler now well known in the art. As disclosed therein wave energy propagating along the main transmission line is coupled to a section of auxiliary line on a frequency selective basis. The auxiliary line is loaded with an element of dielectric material in the coupling region. The dielectric and permeability constants of the element affect the phase constant, and therefore phase velocity, in the auxiliary line and are selected such that the phase constant in the auxiliary line is made equal to the phase constant in the main line at a predetermined and desired frequency or band of frequencies. The equality of phase constants results in wave energy being coupled between the two lines in the band of interest. Outside the band of interest and on either side thereof, the phase velocities of the two lines become unequal by progressively greater amounts. Consequently coupling between the two lines progressively decreases as the frequency is either raised or lowered from the band of interest. It may be seen therefore that the amount of isolation between the two lines is a function of the difference between the phase constants or the phase velocities of the main and auxiliary lines.

The invention disclosed in my copending application therefore provides a suitable means for branching or segregating a given band of frequencies from one transmission path to another while selectively rejecting other frequencies from the auxiliary line. All energy not coupled to the auxiliary line continues to propagate down the main line.

Let us now consider a broad frequency spectrum containing a plurality of frequency bands of interest, bearing intelligence. If it is desired to segregate one intelligence bearing frequency band from the other bands this may be done in accordance with my above-mentioned application by making the phase velocities in the two transmission paths the same as the desired frequency band while separating the phase velocities of the main and auxiliary transmission paths for the other bands. It may be seen therefore that where the frequency bands of interest are substantially separated from each other, the phase velocity difference between the two paths will also be substantial and the undesired frequency bands will not be coupled to the auxiliary line. However, where the intelligence bearing frequency bands are spaced rather closely, there is little opportunity for the phase velocities to differ by a substantial enough amount for the auxiliary line to totally reject all the energy of the undesired bands. As a consequence, where the bands

2

are close together, the desired band will be coupled but also some energy from the undesired bands may also be excited in the auxiliary line.

The present invention constitutes an improvement over my above-mentioned copending application and accordingly it is an object of this invention not only to branch wave energy of a predetermined frequency or band of frequencies but to insure that the segregated energy is totally and completely devoid of all frequencies from specified bands other than that of the desired band.

In accordance with the present invention, two electromagnetic wave transmission paths are coupled along a common length. Coextensive with this common coupling length the auxiliary path is periodically loaded with equal reactive components equally spaced at a distance of one-half wavelength of the lowest frequency to be rejected by the auxiliary guide and to continue down the main guide. This periodic loading is designed to affect the propagation constant of the auxiliary line in a particular way relative to the main line. Furthermore, the dielectric and permeability constants of the reactive components may be fixed so that the phase constants of both lines are equal at the desired frequency or band of frequencies to be coupled to the auxiliary line. The spacing of the equal reactive components results in changing the propagation constant of the auxiliary line from a predominantly imaginary complex number to a predominantly real complex number for the frequency bands to be rejected by the auxiliary line. This situation, in which the imaginary part of the propagation constant is very small while the real part of the propagation constant is very large, is analogous to a nonpropagating system such as a wave guide below cut-off. As a consequence, there can be no coupling between the two lines at those frequency bands. It is to be understood that in this arrangement the lack of excitation of wave energy in the auxiliary line is not due to dissipation of the undesired energy; actually no dissipation of energy occurs at all. The explanation lies rather in the fact that because of the nature of the distributed loading and coupling, wave energy will be completely inhibited from being excited in the auxiliary line. It may be seen therefore that in accordance with the invention, certain predetermined frequency bands will be precluded from being coupled between the lines for either of two reasons; namely, because one of the lines will not support wave propagation for certain frequency bands, or because of the difference between the phase constants of the two lines at those frequency bands.

These and other objects and features, the nature of the present invention, and its various advantages, will appear more fully upon consideration of the specific illustrative embodiment shown in the accompanying drawings and in the following detailed description thereof.

In the drawings:

Figure 1 illustrates a specific embodiment of a frequency selective coupled line branching circuit employing periodically spaced metallic capacitive obstacles; and

Fig. 2, given by way of explanation, shows the characteristic of the ratio of the wave guide phase constant to the phase constant in free space versus frequency for wave transmission lines of different parameters.

Referring more specifically to Fig. 1 a frequency selective coupled line branching circuit in accordance with the invention is shown, by way of example for purposes of illustration, which may be used to segregate or branch on the basis of frequency, one of a plurality of channels of multi-channel wave energy. This circuit comprises a main section 11 of electrical transmission line for guiding wave energy, having terminals A and B. Main line 11 may be a circular wave guide of the metallic shield type proportioned to support a broad frequency spectrum and in particular a plurality of frequency bands of interest.

Located adjacent main line 11 and running for a portion of its length substantially parallel thereto is an auxiliary section 12 of transmission line having terminals C and D. Line 12 may be a rectangular wave guide of the metallic shield type having a wide internal cross sectional dimension proportioned so that line 12 has a cut-off frequency below that of one of the frequency bands of interest supportable in main line 11. Main and auxiliary lines 11 and 12 are in addition proportioned to support the above-mentioned frequencies in a dominant mode field pattern and, in particular, rectangular auxiliary line 11 is proportioned such that the frequency band of interest mentioned above may only be supported in the dominant rectangular mode. Lines 11 and 12 are coupled over a common interval of several wavelengths of said frequency of interest by one of the many broad band coupling means familiar to the directional coupler art. This coupling means may be, as illustrated, a common wall 14 between guides 11 and 12 having a plurality of apertures 15 therein distributed at intervals of less than one-half wavelength of the frequency band of interest supportable in auxiliary guide 12 to be coupled to guide 11. In particular apertures 15 may be of rectangular shape with the wide dimensions of the apertures longitudinally disposed so as to enhance magnetic coupling between the guides and restrict electric field coupling therebetween whereby high directivity of the coupler arrangement is enhanced. The wall thickness of guide 11 is cut away along the portion thereof contiguous to guide 12. Similarly, with the narrow wall of guide 12. Thus, the narrow side wall of guide 12 fits snugly against the contiguous portion of the round guide wall so as to jointly form a common wall of a single rather than a double thickness. Disposed within guide 12 along the length of the coupling region defined by apertures 15, is a plurality of equally dimensioned metallic rods 13. Each of these rods extends from one narrow wall of guide 12 to the other narrow wall thereof, and is parallel to the wide dimension of guide 12. That is, within guide 12 there is disposed a plurality of equal reactances of a capacitive nature. These reactances are equally and periodically spaced along the length of the coupling region. The distance between any one of posts 13 and the next succeeding post is substantially equal to one-half wavelength of the wave energy in the lowest frequency band which is to be rejected by guide 12.

Because of the different shapes and dimensions of guides 11 and 12 in the coupling region, the guides have different propagation constants, phase constants and phase velocity characteristics as a function of frequency. However, because of the loading of guide 12, the phase constant versus frequency characteristics of the two guides intersect at a given frequency to be coupled between the two guides. Accordingly, as disclosed in my above-mentioned copending application, wave energy at the frequency of this intersection is freely and readily coupled between guides 11 and 12. Because of the difference between phase constants at all points other than the region of intersection, wave energy is inhibited from being coupled between the guides to an extent dependent upon the difference between the phase constants of the two guides and because of another effect now to be discussed.

To understand this effect, let us consider Fig. 2. The ordinate of the graph therein depicted is the ratio

$$\frac{\beta_g}{\beta_0}$$

where β_g is the phase constant of wave energy in a wave guide and β_0 is the phase constant of wave energy in free space. The abscissa represents frequency, increasing from left to right. Curve 21 represents, accordingly, the phase constant versus frequency characteristic of the unloaded circular main guide 11. It may be noted, and it is well known in the art, that this characteristic in-

creases from zero at the cut-off frequency, f_c , asymptotically to a constant value of 1.0. Since β_g is related to the phase velocity by the expression

$$v_p = \frac{2\pi f}{\beta_g}$$

curve 21 also defines the phase velocity versus frequency characteristic of guide 11. Curve 22 defines the phase constant versus frequency characteristic of the periodically loaded rectangular auxiliary guide 12. It may be noted that this characteristic has a different cut-off frequency, f_c' , than does curve 21, intersects curve 21 at the center of band f_1 , is discontinuous at periodically spaced intervals f_j, f_k , etc., and rises above the 1.0 value which asymptotically limits curve 21. As taught in my copending application, the point of intersection at the center of the f_1 band and the small regions immediately adjacent on either side thereof, wherein curves 21 and 22 are very close together, define a frequency band f_1 wherein the phase velocities of guides 11 and 12 are substantially equal and wherein coupling between the two guides freely takes place. Elsewhere, at other frequencies, coupling is inhibited as a function of

$$\Delta\left(\frac{\beta_g}{\beta_0}\right)$$

which is the difference between the phase constants of the two guides in the ratio form above defined. However, coupling is also inhibited and indeed effectively completely inhibited in those frequency bands defined by the discontinuous regions of curve 22. Let us now consider the nature of the discontinuous regions. The frequency band f_j is that frequency for which the spacing between reactive elements 13 of Fig. 1 is substantially equal to one-half wavelength; f_k is the frequency band for which said spacing is substantially equal to one whole wavelength, etc. It may be seen therefore that the discontinuous regions of curve 22 are harmonically spaced and that the wavelength at the center of any n th discontinuous region (counting from the f_j discontinuous region) is substantially equal to

$$\frac{\lambda_j}{n+1}$$

where λ_j equals the wavelength at the center of frequency band f_j . Accordingly, the frequency of any n th discontinuous region equals

$$(n+1)f_j$$

Now the significance of the discontinuous or stop band regions just described is best understood by considering what happens to the propagation constant in guide 12 as frequency changes. As is well known, the propagation constant is a complex function defining the attenuation and phase characteristics of electromagnet wave energy. Specifically, the propagation constant, λ , is equal to the attenuation constant, α , plus an imaginary component $i\beta$, where β is the phase constant. In the regions between the stop bands, α in loaded guide 12 is very close to zero while β , as can be seen from curve 22, is large except at the cut-off frequency. Thus, the propagation constant λ in between the stop bands is predominantly imaginary since $\lambda = \alpha + i\beta$. In the stop bands however, the attenuation constant α becomes very large. Effectively, this results from β becoming a substantially imaginary quantity. As a consequence, λ is predominantly real in the stop bands. Therefore, at certain stated frequency bands determinable by the spacing between the periodic reactances, as indicated above, the propagation constant of guide 12 becomes predominantly real, that is, the attenuation constant α becomes very large and the phase constant β becomes very small. Therefore, guide 12 is nonpropagating for those frequency bands at which this parameter relationship exists. Accordingly, therefore, coupling between guides 11 and 12 is substantially com-

5

pletely inhibited in stop bands f_j , f_k , etc. Now, then, if f_1 , f_j and f_k represent intelligence bearing frequency bands supported by wave guide 11, f_1 will be coupled between the lines because of the equal phase constants existing in the lines at f_1 but intelligence bearing frequency bands f_j and f_k will be precluded from being coupled between the guides since guide 12 is nonsupportive of those bands. Accordingly, f_j and f_k will continue propagating along wave guide 11 past the coupling region while f_1 will be decoupled from guide 11 and excited in guide 12.

At this point we are prepared to consider the overall operation of the embodiment of Fig. 1. Consider a frequency spectrum including bands or channels f_1 , f_j and f_k entering wave guide 11 at terminal A. This wave energy will propagate along guide 11 until the coupling region defined by apertures 15 is reached. At this region f_1 will be coupled to guide 12 which, because of the directional coupler characteristics of the embodiment, will propagate along guide 12 to terminal C. Channels f_j and f_k however will continue along guide 12 to terminal B. It should be noted that the channel branching circuit of Fig. 1 is bilateral and symmetrical. Thus, if the several frequency channels including f_1 are applied to terminal B, f_1 will be branched into guide 12 to terminal D and the remaining f_j and f_k will be passed to terminal A of guide 11. Conversely, if f_1 were applied to terminal D and f_j and f_k to terminal A, the signals would all be combined in wave guide 11 at terminal B. If in a particular arrangement one or more of the terminals are not employed, they may be appropriately connected to a non-reflecting dissipative termination. Thus, the frequency selective wave coupling system may either be utilized for abstracting a given frequency band from a given spectrum or for combining a frequency band with other frequency bands of different value.

As indicated above and as discussed in detail in my above-mentioned copending application, the pass band, that is, the band coupled to the auxiliary line, is a function of the dielectric constant and/or permeability constant of the material loading the auxiliary line relative to the unloaded main line. It has been pointed out that the location of the stop bands in the frequency spectrum is a function of the spacing between the reactive components in the auxiliary line. Since these parameters upon which the pass and stop bands are dependent may be individually and separately determined and proportioned, the spacing of the reactive components may be proportioned so that a stop band may be located as close to a desired pass band as may be desirable in the system utilizing the frequency selective coupler. Indeed, by proper selection of the dielectric constant and/or permeability constant of the material comprising the reactive components and by an appropriate spacing of the components, the stop band may be located either below or above the pass band frequency and as close or far away from the pass band as desired. The functional versatility thus inherent in the invention is apparent.

Since a major function of the reactive components is to make the propagation constant of the auxiliary line predominantly real, for specified frequency bands, and since this function depends primarily on the spacing between the components rather than the precise nature of the reactive components themselves, a substantial latitude is permissible in the type of reactive components which may be utilized in accordance with the invention. The capacitive rods of Fig. 1 are admirably suited for the purpose. However, where the structural arrangement of the particular system involved makes it desirable, other reactive components may be utilized, which may be, for example, inductive posts (posts parallel to the narrow wall of the wave guide) or dielectric windows extending completely transversely across the auxiliary line. Furthermore, any material that would appropriately affect the phase constant of the auxiliary line relative to the main

6

line so as to create a pass band and which would also provide a predominantly real propagation constant in the auxiliary line for the other bands, would be appropriate.

In Fig. 1 the transmission lines disclosed were of the metallic shield type with the main line having a circular cross section and the auxiliary line a rectangular cross section. However, it is to be understood that the principles of the invention are equally applicable to various other types of transmission paths. For example, a rectangular metallic wave guide may be loaded as an auxiliary line so as to match, in accordance with the invention, an all-dielectric main wave guide, or a coaxial wave guiding structure, or another rectangular metallic guide of different proportions from the auxiliary rectangular guide in the coupling region. Furthermore, the wave energy may be in the form of any mode desired provided of course the coupling means between the two transmission paths are appropriate for the particular mode of interest. Various types of coupling apertures and mechanisms are well known in the art to correspond to particular types of mode patterns.

In all cases, it is understood that the above-described arrangements are simply illustrative of a small number of the many possible specific embodiments which could represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A frequency selective wave coupling system comprising a section of circular hollow metallic wave guide, a section of rectangular hollow metallic wave guide, said circular and rectangular wave guides extending in a common direction with a narrow wall of said rectangular guide disposed contiguous to a common length of said circular guide's wall, said circular guide supportive of a broad range of frequencies comprising a plurality of spaced frequency bands of interest, a series of rectangular coupling apertures disposed in said common length of wall, a series of equally dimensioned metallic rods disposed within said rectangular guide, said series of rods extending along at least a length of said rectangular guide substantially coextensive with said series of apertures, said rods being individually disposed parallel to the wide dimension of said rectangular guide and extending from one narrow wall of said rectangular guide to the other, said rods being spaced from each other in a longitudinal direction with respect to said rectangular guide with each rod spaced a given distance from a next succeeding rod equal to one-half wavelength of a frequency within one of said bands of interest so as to periodically load said rectangular wave guide in the coupling region.

2. A frequency selective wave coupling system comprising first and second sections of electromagnetic wave transmission line disposed parallel and adjacent to each other, said first transmission line supportive of a range of frequencies comprising two closely spaced frequency bands of interest, said first and second lines having different and predominantly imaginary propagation constants, a first means for coupling said first and second lines to each other, and a second means for equalizing the respective imaginary portions of said propagation constants of said lines for one of said frequency bands of interest and simultaneously for making the propagation constant of said second line predominantly real over a limited frequency interval substantially coextensive with the other of said bands of interest, whereby said one frequency band is coupled between said first and second lines while said lines are isolated from each other at the other of said frequency bands of interest.

3. A combination as recited in claim 2 above wherein said second means comprises a periodically disposed series of equally spaced reactive components in said second

transmission line, with all of said reactive components having the same value of reactance, and with each of said components spaced from a next succeeding component by a distance equal to one-half wavelength of the middle frequency of said other frequency band of interest.

4. A frequency-selective wave coupling system comprising first and second sections of hollow metallic wave guide disposed parallel to each other and extending in a common direction with said guides contiguous to each other along a common length of wall also extending in said common direction, said first guide supportive of a broad range of frequencies comprising a plurality of spaced frequency bands of interest, said first and second guides having different and predominantly imaginary propagation constants, a series of coupling apertures disposed in said common length of wall, and means for equalizing the respective imaginary portions of said propagation constants of said guides for a given frequency band of interest in said range and for making the propagation constant of said second guide predominantly real for the remainder of said plurality of bands of interest comprising a series of periodically spaced reactances disposed solely in said second guide with said series of reactances extending longitudinally along a length of said second guide, said length of said second guide being substantially co-extensive with said series of coupling apertures.

5. A combination as recited in claim 4 wherein said periodically spaced reactances are spaced apart by one-half wavelength of the middle frequency of the lowest frequency band of said remainder of said plurality of bands.

6. A frequency selective wave coupling system comprising first and second sections of hollow metallic wave guide disposed parallel to each other and extending in a common direction with said guides contiguous to each other along a common length of wall also extending in said common direction, a series of coupling apertures disposed in said common length of wall, and a series of periodically spaced reactive components disposed solely in second guide with said series of reactive components

extending longitudinally along a length of said second guide, said length of guide being substantially coextensive with said series of coupling apertures.

7. A combination as recited in claim 6 wherein said reactive components comprise metallic rods individually extending transversely and completely across said second guide.

8. A combination as recited in claim 7 wherein said metallic rods all have the same physical dimensions.

9. For use in a wave transmission system, a combination comprising, first and second sections of electromagnetic wave transmission line disposed parallel and adjacent to each other, said first transmission line supportive of a broad range of frequencies comprising a plurality of spaced frequency bands of interest, said first and second lines having predominantly imaginary propagation constants, a first means for coupling said first and second lines to each other, and a second means for making the propagation constant of said second line predominantly real for at least one given band of said plurality of bands of interest comprising a series of periodically spaced reactive components disposed solely in said second transmission line, with each of said components spaced from a next succeeding component by a distance equal to one-half wavelength of the middle frequency of said one given band of said plurality of frequency bands of interest.

References Cited in the file of this patent

UNITED STATES PATENTS

2,527,477	Clapp	Oct. 24, 1950
2,562,281	Mumford	July 31, 1951
2,588,832	Hansell	Mar. 11, 1952
2,615,982	Zaslavsky	Oct. 28, 1952
2,739,288	Riblet	Mar. 20, 1956
2,744,242	Cohn	May 1, 1956

FOREIGN PATENTS

976,704	France	Nov. 1, 1950
663,820	Great Britain	Dec. 27, 1951