May 10, 1960 P. G. MARIÉ 2,936,430

WIDE BAND RESONANT DIRECTIONAL COUPLERS

Filed June 15, 1956 2 Sheets-Sheet 1

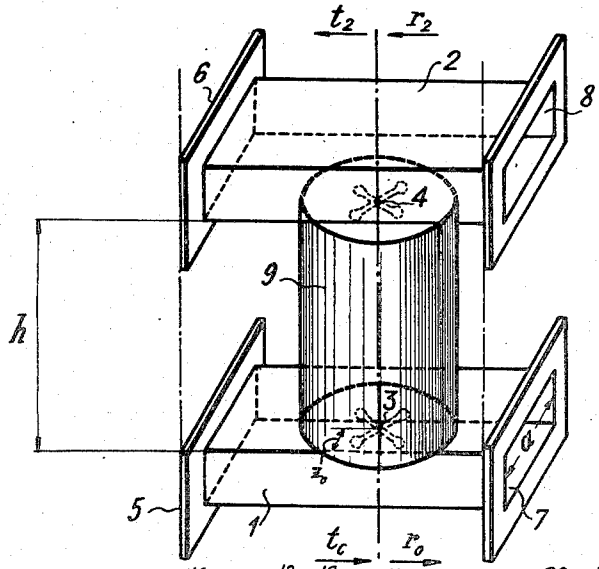



Fig. 1

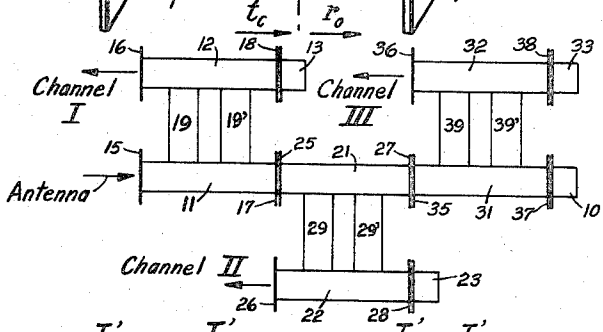



Fig. 5

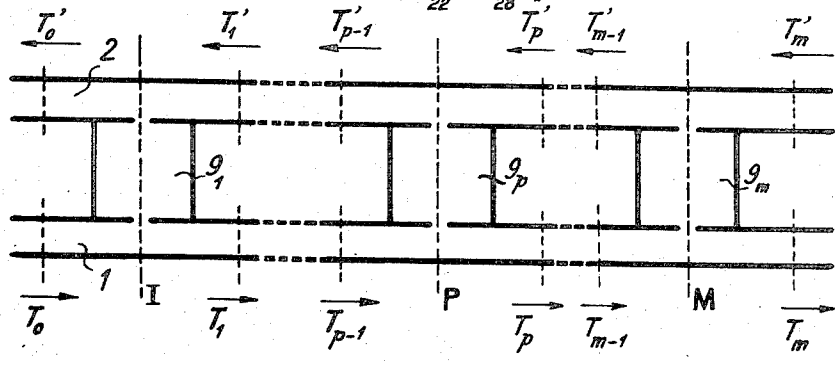



Fig. 2

INVENTOR
PIERRE G. MARIÉ

BY
Pennie Edmonds Morton Barrows & Taylor

ATTORNEYS

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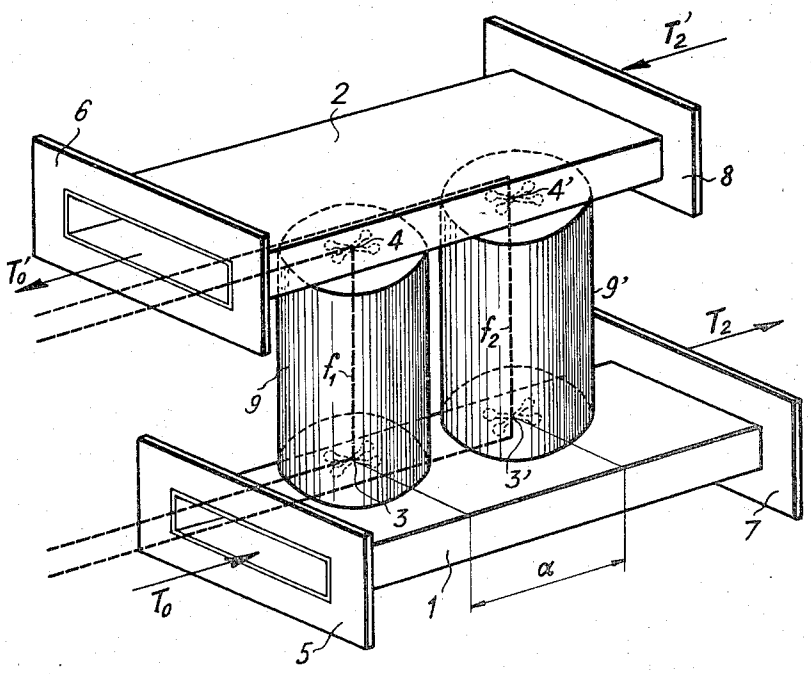



Fig. 3

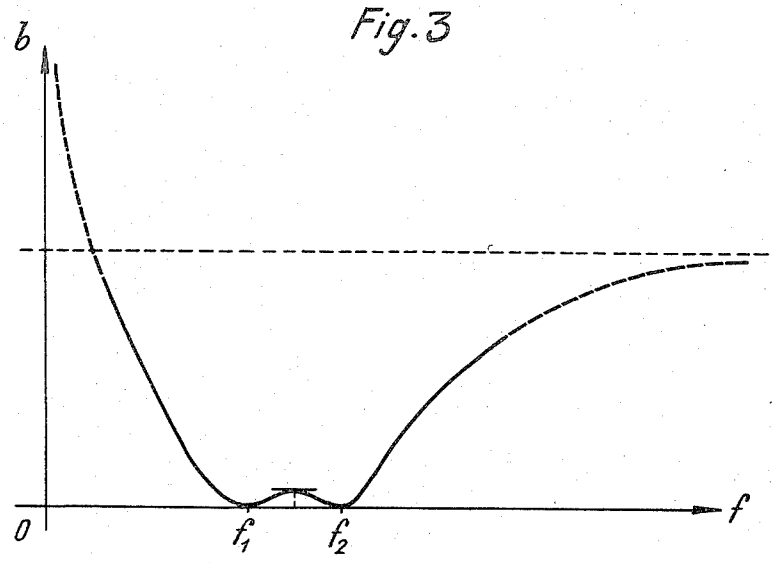



Fig. 4

INVENTOR
PIERRE G. MARIÉ

BY Pennie Edmonds Morton Barrows & Taylor

ATTORNEYS

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# WIDE BAND RESONANT DIRECTIONAL COUPLERS

Pierré G. Marié, Paris, France

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Claims priority, application France June 18, 1955

3 Claims. (Cl. 333—10)

The present invention relates to wide band frequency selective directional couplers for microwaves.

In applicant's copending application Serial No. 416,869 filed March 17, 1954, there are disclosed frequency selective directional couplers comprising two rectangular wave guides coupled to each other through a circular wave guide stub which forms a resonant cavity. Such couplers may be termed "double biquadratic wave guide couplers." Each coupling between a rectangular wave guide and the circular wave guide stub is so established that a wave propagated down the rectangular guide in question and arriving at the vicinity of the coupling undergoes a division of its energy into two parts. The first part is further propagated within the rectangular guide beyond the junction with the stub. The second part is radiated into the circular guide through a system of coupling slots which are disclosed in that application. The energy thus passing into the circular guide appears there as a circularly polarized wave comprising two $TE_{11}$ waves which are polarized perpendicularly and which are in quadrature. The sense of rotation of this circularly polarized wave depends upon the direction of propagation of the energy within the rectangular guide from which the energy passes into the circular wave guide stub.

The resonant cavity provided by the circular wave guide stub can be tuned to a selected frequency of resonance in order that the coupler may be traversed only by energy lying within a band of frequencies centered on the resonant frequency.

There are further described in the above-identified application groups of couplers of the type just described but having one rectangular guide in common. These devices, which may be termed multichannel filters, hence include a common rectangular wave guide adapted to support waves covering a wide band of frequencies from which it is desired to extract separately particular bands or channels of energy, and a plurality of circular wave guide stubs all coupled at one end to the common rectangular wave guide, each of these stubs being coupled at its other end to a separate rectangular guide. These circular wave guide stubs act as cavity resonators and are tuned to the mid-frequencies of the several channels for which they are provided, and in each case the energy within such a channel or band may be obtained at one end of the separate rectangular wave guide coupled to such cavity.

These directional couplers have a filtering or frequency selective property, the frequency selecting property being the resonance curve of the cavity. In the prior art, there were disclosed couplers having a wide bandwidth which comprise two rectangular wave guides coupled together by means of a plurality of cavity resonators tuned to different frequencies lying within the band of frequencies to be transmitted through the coupler and spaced along the rectangular wave guides at quarter wavelength intervals, the wavelength of reference being the central wavelength of



the band. In these couplers of the prior art, each individual cavity resonator which conveys a single mode wave does not form with the rectangular guides a directional coupler. Directional coupling results merely from the spacing of the adjacent resonators at quarter wavelength intervals. Since the adjacent resonators are tuned to different frequencies, there is not exactly an opposition of phase between two waves passing through a pair of such adjacent resonators and which are to be cancelled in a given direction of the output rectangular wave guide. Neither is there a concordance of phase between those two waves which are to be reinforced in the other direction of the output rectangular wave guide.

It is an object of the present invention to provide frequency selective directional couplers having a wide band width and having frequency selection characteristics better than those of the resonance characteristics of the cavities.

According to the invention directional couplers of the type disclosed in the above-identified and in the present applications and having suitably spaced resonant-frequencies are combined to provide plural-cavity coupling and filtering units. However whereas in the prior art the combination of plural directional couplers was so made as to provide for a given frequency channel a single resonant cavity, according to the present invention there are provided for any given channel a plurality of cavities which can be either cylindrical or annular, whose resonance frequencies are graduated one after another, and whose number depends upon the attenuation frequency characteristic desired for the filter.

The invention will now be further described in detail with reference to the accompanying drawings in which:

Fig. 1 is a diagrammatic perspective view of a directional coupler having a single resonant cavity of the type disclosed in copending application Serial No. 416,869;

Fig. 2 is a diagram useful in explaining the operation of filtering couplers according to the invention incorporating couplers of the type illustrated in Fig. 1;

Fig. 3 is a diagrammatic perspective view of a particular form of filtering directional coupler of the type of Fig. 2;

Fig. 4 is a graph describing certain properties of the coupler of Fig. 3; and

Fig. 5 is a diagram of a switching filter including a plurality of frequency selective directional couplers of the type illustrated in Fig. 3.

Referring to Fig. 1 which illustrates a directional coupler of the type disclosed in my copending application above identified, reference characters 1 and 2 indicate two rectangular wave guides whereas 9 is a circular wave guide stub connecting the two rectangular guides together at their wide faces, and 3 and 4 are systems of coupling slots between the rectangular guides and the circular wave guide stub. The slot systems may include each two perpendicular slots of dumbbell shape, the centers of these slots being disposed on the axis of the circular guide although not on the axis of the rectangular guides. Rather these centers are displaced from the center line of the wide face of the rectangular guides by a quantity $z_0$ given by the relation:

$$\operatorname{Tan} \frac{\pi}{a} z_0 = \frac{2a}{\lambda_g}$$

in which $a$ is the width dimension of the rectangular guide and $\lambda_g$ is the wave length of the wave in that guide.

If $t_0$, $r_0$, $t_1$, $r_1$, $t_2$, $r_2$ represent the intensities of the waves in the guides 1 and 2 on opposite sides of the plane containing the axis of the circular guide 9 and perpendicular to the length of the rectangular guides and in the guide 9, it can be shown as set forth in the copending ap-

plication above identified that these intensity magnitudes are related by the following matrix relation:

$$\begin{vmatrix} t_0 \\ r_0 \end{vmatrix} = \|T\| \times \begin{vmatrix} t_1 \\ r_1 \end{vmatrix} = \|T\|^2 \times \begin{vmatrix} t_2 \\ r_2 \end{vmatrix} \quad (1)$$

with

$$\|T\| = \begin{vmatrix} \frac{-e^{j(2\theta-u)}}{j \sin u} & j \cot u \\ -j \cot u & \frac{e^{-j(2\theta-u)}}{j \sin u} \end{vmatrix}$$

Here $u$ is the impedance angle of the slots and $\theta$ is the half angle of the phase change of the wave in the circular guide.

The coefficient of transmission $\tau$ is given by

$$\tau = \frac{t_1}{t_0} = \frac{\sin^2 u e^{-j2(2\theta-u)}}{1-\cos^2 u e^{-j2(2\theta-u)}} \quad (2)$$

and the coefficient reflection $\rho$ is given by

$$\rho = \frac{r_0}{t_0} = j\frac{2 \sin (2\theta-u) \cos u e^{-j2(2\theta-u)}}{1-\cos^2 u e^{-j2(2\theta-u)}} \quad (3)$$

Equations 2 and 3 for $\tau$ and $\rho$ show that if

$$(2\theta-u)=k\pi$$

$k$ being an integer, then

$$\tau=1 \text{ for } \rho=0$$

This means that all of the energy is transmitted.

If $\theta$ is expressed as a function of the height $h$ of a cavity thus:

$$\theta=\frac{\pi h}{\lambda_g}$$

then

$$h=\left(k+\frac{u}{\pi}\right)\frac{\lambda_g}{2}$$

The last expression makes it possible either to determine the height $h$ of the cavity in order to give to it a desired resonant frequency $f_1$ or else to calculate the resonant frequencies of the cavity for different values of $k$, $h$ being fixed.

It is appropriate to consider how the coefficients of transmission $\tau$ and reflection $\rho$ vary in the vicinity of the resonant frequency $f_1$.

Let $d\theta$ be the variation in $\theta$ accompanying a variation from $f_1$ of the frequency of the waves propagated within the directional coupler. In view of the expression for the wavelength in the guides one may write

$$\frac{d\theta}{\theta}=\frac{f-f_1}{f_1}\left(\frac{\lambda_g}{\lambda}\right)^2$$

$\lambda$ being the wave length in free space.

If $u$ is small, the intensities of the waves transmitted and reflected vary rapidly about resonance and it is possible for a first approximation to replace Equations 2 and 3 by the following:

$$\tau=\frac{t_1}{t_0}=\frac{1}{1+jQ_1\frac{f-f_1}{f-f_1}}e^{-j(4\theta-2u)} \quad (4)$$

$$\rho=\frac{r_0}{t_0}=\frac{jQ_1\frac{f-f_1}{f_1}}{1+jQ_1\frac{f-f_1}{f_1}}e^{-j(4\theta-2u)} \quad (5)$$

Equations 4 and 5 are obtained by replacing the functions of $\theta$ by first order expansions of $d\theta$ and by setting:

$$Q_1=\frac{4K\pi}{\tan^2 u}\left(\frac{\lambda_g}{\lambda}\right)^2 \quad (6)$$



Equations 4, 5 and 6 make it possible to write the square of the matrix $\|T\|$ in the form:

$$\|T\|^2=\begin{vmatrix} 1+jQ_1\frac{f-f_1}{f_1} & -jQ_1\frac{f-f_1}{f} \\ jQ_1\frac{f-f_1}{f_1} & 1-jQ_1\frac{f-f_1}{f_1} \end{vmatrix} \quad (7)$$

Accordingly to the invention as schematically illustrated in Fig. 2 a plurality of cylindrical cavities $9_1 \ldots 9_p, \ldots 9_m$ having resonant frequencies $f_1, \ldots f_p, \ldots f_m$ are associated with the rectangular guides **1** and **2**. The resulting structure appears as a plurality of directional couplers I, . . . P, . . . M of the type illustrated in Fig. 1 connected in series, rectangular guides being assumed to possess the length corresponding to an electrical angle $\alpha$.

If $T_0, T_1, \ldots T_{p-1}, T_p, \ldots T_{m-1}, T_m$ represent the intensities of the waves at the entrance planes, at the planes of coupling of the couplers and at the output planes of guide **1** and if $T'_0, T'_1, \ldots T'_{p-1}, T'_p, \ldots T'_{m-1}, T'_m$ represent the intensities of the waves at the planes of exit, of coupling for the successive couplers and at the exit from the guide **2**, one may write

$$\left.\begin{aligned} T_{p-1}&=t_0 e^{\frac{j\alpha}{2}} \\ T_p&=r_0 e^{\frac{-j\alpha}{2}} \\ T'_{p-1}&=t_1 e^{\frac{-j\alpha}{2}} \\ T'_p&=r_1 e^{\frac{j\alpha}{2}} \end{aligned}\right\} \quad (8)$$

By combining Equations 1, 7 and 8 one may obtain the following matrix relation:

$$\begin{vmatrix} T_{p-1} \\ T'_{p-1} \end{vmatrix} = \left\| v+\frac{w}{Q_p\frac{f-f_p}{f_p}} \right\| \times \begin{vmatrix} T_p \\ T'_p \end{vmatrix}$$

if one sets

$$v=\begin{vmatrix} e^{j\alpha} & 0 \\ 0 & e^{-j\alpha} \end{vmatrix}$$

$$w=\begin{vmatrix} -je^{j\alpha} & j \\ -j & je^{-j\alpha} \end{vmatrix}$$

The matrix for the filter of Fig. 6 then assumes the form

$$\begin{vmatrix} T_0 \\ T'_0 \end{vmatrix} = \left\| \prod_{P=1}^{P=m} v_p+\frac{w_p}{Q_p\frac{f-f_p}{f_p}} \right\| \times \begin{vmatrix} T_m \\ T'_m \end{vmatrix} \quad (9)$$

The matrix (9) becomes much simplified in certain special cases.

Fig. 3 represents a filter in which $p=2$ and

$$\alpha=\frac{\pi}{2}$$

It includes the rectangular guides **1** and **2**, the cylindrical cavity **9** coupled to the guides by the systems of slots **3** and **4**, and the cylindrical cavity **9'** coupled to the rectangular guides by slot systems **3'** and **4'**.

The two rectangular guides are parallel, and the energy generated in the second rectangular guide is propagated therein in a direction opposite to the sense of propagation in the first guide. For a frequency $f$ between the frequencies $f_1$ and $f_2$, part of the energy is transmitted by the cavity **9** and the other part by the cavity **9'**. The difference between the phase shifts undergone by these energies in passage through the circular guides is equal to $\pi/2$ since one of the guides is detuned to lead and the

other to lag. In the course of the passage through the rectangular guides the phase separation between the two parts of the energy amounts to $2\alpha=\pi$. The total phase separation is hence $3\pi/2$.

Matrix (9) then assumes the form

$$\begin{vmatrix} T_0 \\ \\ T_0' \end{vmatrix} = \left[ -\begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix} + \frac{\begin{vmatrix} j & 1 \\ 1 & -j \end{vmatrix}}{Q_1\frac{f-f_1}{f_1}} + \frac{\begin{vmatrix} j & -1 \\ -1 & -j \end{vmatrix}}{Q_2\frac{f-f_2}{f_2}} - \frac{2\begin{vmatrix} 1 & j \\ -j & 1 \end{vmatrix}}{Q_1Q_2\frac{f-f_1}{f_1}\frac{f-f_2}{f_2}} \right] \begin{vmatrix} T_2 \\ \\ T_2' \end{vmatrix} \quad (10)$$

If the quality factors are equal and if the frequencies $f_1$ and $f_2$ are close enough so that their arithmetical mean may be taken to be equal to their geometric mean, it is possible to write:

$$\left.\begin{aligned} d&=\frac{2f-f_1-f_2}{f_2-f_1} \\ Q&=Q_1=Q_2 \\ \beta&=Q\frac{f_2-f_1}{f_2+f_1} \end{aligned}\right\} \quad (11)$$

If moreover $T'_2$ is assumed equal to zero, one may write as relations between the squares of the moduli for $T_0$, $T_2$ and $T'_2$ the following:

$$\left.\begin{aligned} \frac{1}{|\rho|^2}&=\frac{|T_0|^2}{|T_2|^2}=1+\frac{4(\beta^2+1)}{\beta^4(d^2-1)^2} \\ \frac{1}{|\tau^2|}&=\frac{|T_0|^2}{|T'_0|^2}=1+\frac{\beta^4(d^2-1)^2}{4(\beta^2+1)} \end{aligned}\right\} \quad (12)$$

If B designates the composite attenuation of the filter then:

$$B=20\log\left|\frac{1}{\tau}\right| db$$

Fig. 4 represents the variation of B as a function of the frequency. In view of the approximations made in the above analysis, it is only the central portion of this curve which can be relied upon.

Fig. 5 represents a multichannel filter made up of frequency selective directional couplers of the type shown in Fig. 3. The filter of Fig. 5 makes it possible to extract from a wave of wide frequency make-up electromagnetic energy fractions corresponding to three channels.

The filter of Fig. 5 comprises a first frequency selective directional coupler including the rectangular guides **11** and **12** and the two cylindrical cavities **19** and **19'**. It also comprises a second frequency selective directional coupler including the rectangular guides **21** and **22** and the cylindrical cavities **29** and **29'**, and a third frequency selective directional coupler including the rectangular guides **31** and **32** and the cylindrical cavities **39** and **39'**. The rectangular guides **11, 21** and **31** are aligned at their ends **17, 25** and **27, 35**. Electromagnetic energy from an antenna not shown enters the coupler at the mouth **15** of the guide **11**. Energy appropriate to the first channel emerges at the mouth **16**. That appropriate to the second channel emerges at the mouth **26** and that appropriate to the third channel emerges at the mouth **36**. The mouths **18, 28** and **38** of the rectangular guides **12, 22** and **32** and also the mouth **37** of the rectangular guide **31** are closed by dissipative load elements **13, 23, 33** and **10**.

I claim:

**1. A resonant directional wave guide coupler comprising an input rectangular wave guide section open at both ends, an output rectangular wave guide section of the same cross-sectional dimensions parallel thereto, open at both ends, and a plurality of cylindrical cavity resonators having their axes perpendicular to the wide sides of said rectangular guides, distributed both in space and resonant frequency in such a way that the electrical angle in both rectangular guides between two successive cavity resonators is substantially equal to a quarter wave length for a frequency between the resonant frequencies of said successive circular resonators, each of said circular cavity resonators being coupled to said input and output wave guides by means of apertures centered about points at each of which the longitudinal and transverse magnetic field components are equal in amplitude and in phase quadrature, whereby to one sense of propagation in each of the rectangular guides corresponds a definite sense of rotation of the wave in said circular cavity resonators, and a reverse coupling is effected between said input and output rectangular wave guides.**

**2. A wide band resonant directional wave guide coupler comprising an input wave guide of rectangular cross-section, said input wave guide being open at both ends and being adapted to support individual traveling waves in both directions, an output wave guide having the same cross-section as said input wave guide and being disposed parallel to said input wave guide, a plurality of individual resonant frequency cavity resonators of circular cross-section adapted each to support individual circularly polarized waves in both senses of rotation inserted between said input and output wave guides adjacent of said resonators being distant from one another by a distance substantially equal to a quarter wave length in said input and output wave guides for a frequency equal to the mean value of the resonant frequencies of said adjacent resonators, and means to couple an individual circularly polarized wave in each cavity to an individual traveling wave in both input and output wave guides.**

**3. A wide band resonant directional wave guide coupler according to claim 2 in which said means comprise apertures in the wide faces of said input and output wave guides symmetrically disposed with respect to the axis of such cylindrical cavity resonator, said apertures being further centered on points in the wide faces of said input and output wave guides at which the longitudinal and transverse magnetic fields of said individual traveling waves are equal in amplitude and are in phase quadrature.**


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