Aug. 9, 1949. E. M. PURCELL 2,478,317

DIRECTIONAL COUPLER

Filed July 9, 1945

FIG. 1

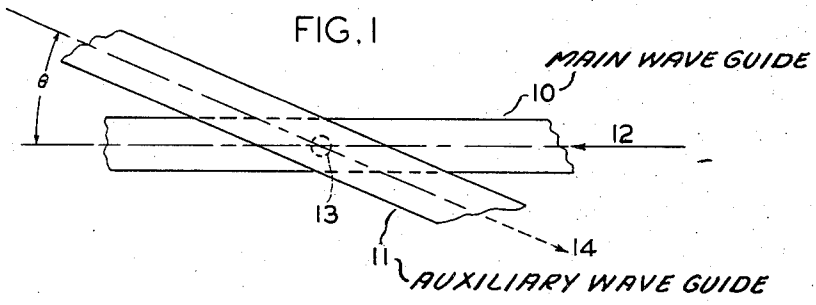


FIG. 2

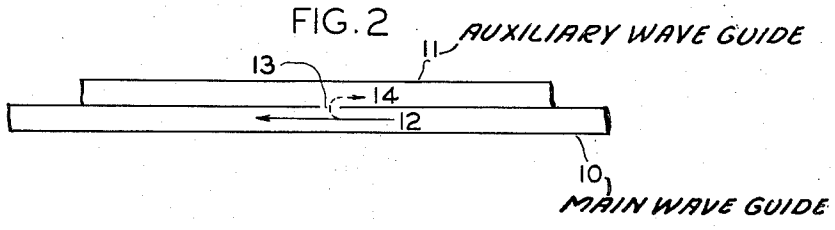
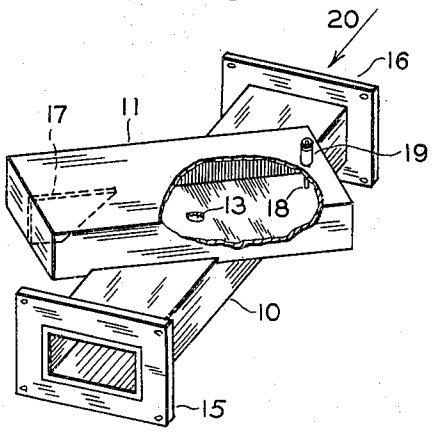


FIG. 3



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DIRECTIONAL COUPLER

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4 Claims. (Cl. 178—44)

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This invention relates to an electrical apparatus and more particularly to an improved microwave energy directional coupler.

A description of a one-hole type of directional coupler has been given in an application of Hans A. Bethe entitled "Electrical apparatus," filed April 24, 1945, and bearing Serial No. 590,047. The directional coupler there shown includes two parallel lengths of wave guide which are interconnected and coupled by an aperture in a common wall. The common wall and the walls parallel thereto are perpendicular to the direction of the electric fields existing within the wave guides; such walls are generally the wider walls of the wave guides and are hereinafter so considered.

The directional coupler there shown functions in such manner that a primary wave traveling in a transmission line including one length of coupler wave guide, hereinafter termed the main guide, produces secondary waves in the other length of coupler wave guide, hereinafter termed the auxiliary guide. Further, the secondary wave energy excited in one section (the length of guide extending in one direction from the coupling aperture) of the auxiliary guide is negligibly small as compared to that excited in the other section (the length extending in the other direction from the coupling aperture). This condition of high selectivity or directivity is achieved by suitable cross-sectional dimensioning of the component wave guides so that the wider walls have certain critical dimensions. In the instance where it is desired that the wider walls of the main and auxiliary guides be equal, theoretically complete directivity is obtained when the width of the said walls is 0.707 of the free-space wave length of the microwave energy involved.

Special sizes of wave guides must therefore be utilized for the directional coupler described above, for directional couplers so dimensioned are rarely of the same cross-sectional size as the transmission line with which they are to be used. It then also becomes necessary to provide impedance matching means between the directional coupler and the transmission line for satisfactory performance.

It is an object of the present invention to provide a directional coupler whose main guide may have the same cross-sectional dimensions as the transmission line to which the directional coupler is to be connected.

It is another object to provide a directional coupler in which high directivity is achieved as a result of a suitable angular relation between the component wave guides.

It is still another object of the invention to provide a directional coupler which may be adjusted to have high directivity at any frequency within a selected microwave band.

Several advantages are secured by the present

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invention. The structure of the directional coupler hereinafter described is mechanically simple, and its wave guide components may generally be made from the same stock wave guide utilized for the transmission line of a microwave system. Matching problems are eliminated and special matching structures become unnecessary. High directivity may be achieved without the necessity of providing specially dimensioned directional coupler components. Furthermore, high directivity may be obtained at any microwave frequency within a working band, by a corresponding angular adjustment of the directional coupler components.

These and other objects and advantages will become apparent from the following description when read in connection with the drawing, in which:

Fig. 1 is a schematic diagram representing a top view of component wave guides of a directional coupler in accordance with the present invention;

Fig. 2 is a schematic diagram representing a longitudinal section of Fig. 1; and

Fig. 3 is a cut-away isometric view of a directional coupler embodying the invention.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

Referring now to Figs. 1 and 2 of the drawing, reference numerals 10 and 11 designate main and auxiliary guides, respectively each having a rectangular cross section. Electric lines of force exist within the wave guides during excitation, and in the embodiment here shown the wave guides are so proportioned that the walls perpendicular to these lines of force are the wider walls of the wave guides.

The main and auxiliary guides are assembled with a wider wall of one in contact with a wider wall of the other, thus forming a partition or wall which is common to the main and auxiliary guides. The common wall may alternatively be formed of a single sheet of suitably thin material as later described. An aperture 13 through the common wall provides electromagnetic coupling between the main and auxiliary guides, whereby wave energy in the main guide induces or excites wave energy in the auxiliary guide.

The component wave guides are further adapted to be angularly displaced, with respect to each other, about an axis passing through the center of aperture 13 and perpendicular to the common wall. The angle θ between the longitudinal axes of the wave guides, as seen in the plan view given in Fig. 1, may thus be adjusted to a suitable value for high directivity at the operating frequency as will hereinafter appear.

As a matter of general practice it is the incident primary wave from which coupling is de-

sired, and such a wave is shown traveling from right to left in wave guide 10 as indicated by the full-line arrow 12 in Figs. 1 and 2 of the drawing. The corresponding reflected primary wave is not here shown, but it is to be understood that as is usual in practical microwave systems its magnitude is small as compared to the incident primary wave, and that it travels in the opposite direction in wave guide 10.

For a given wave length of energy involved, an angle θ may be selected which provides high directivity in the described structure. At such an angle θ, the incident primary wave 12 in main guide 10 excites a secondary wave 14, of proportional magnitude, in one section of the auxiliary guide as shown. The path, which may be traced along the direction of travel of the primary wave, thence through the coupling aperture and along the direction of travel of the secondary wave, includes an acute angle as may be noted by reference to Fig. 1. The direction of travel of the secondary wave with respect to the corresponding primary wave is therefore here defined as backwardly directed, and the section of auxiliary guide in which the secondary wave is excited is similarly defined as backwardly extending, hereinafter also termed the wave-propagating section.

The component wave guides may be angularly displaced through such an angle θ that substantionally all of the secondary energy travels backwardly with respect to the primary wave from which it is excited, very little energy being excited in the forwardly extending section of the auxiliary guide. The optimum value of θ at which such high directivity is secured is determined by the operating frequency, the thickness of the common wall, and the size and shape of the coupling aperture. In general, the optimum value of angle θ increases as the thickness of the common wall increases, and decreases as the wave length of the energy involved increases. The optimum value of angle θ also decreases as the size of the coupling aperture increases; the size of the aperture itself is primarily determined by the amount of coupling desired, and varies directly with it. It has been found that for rectangular waveguides having outside dimensions of ½ inch by ¼ inch with a wall thickness of .04 inch the optimum values of θ vary between the values of 75 degrees and 55 degrees as the diameter of aperture 13 varies from 1 millimeter to 4 millimeters. These values of θ are for a thickness of the common wall of .04 inch. If the thickness of the common wall is decreased to .005 inch the range of values of θ for the same range of diameters becomes 49 degrees to 42 degrees being larger for the smaller diameters. For still other values of wall thickness, aperture size, etc. the value of θ may vary from 90 degrees to less than 30 degrees. The optimum value of θ for a particular set of conditions is best determined experimentally, using the above values as a guide.

The high directivity obtained in the directional coupler here described is a result of interaction of the electric and magnetic field components at the coupling aperture. The relative strength of these field components, which interfere constructively and destructively in the backward and forward directions, respectively, along the auxiliary guide, is determined by the angle θ between the longitudinal axes of the component wave guides. Theoretically, an optimum value of the angle θ causes elimination of a forwardly directed secondary wave. As a practical matter, however, a very small secondary wave may nevertheless exist in a forwardly extending section, but may be regarded as having substantially zero value as compared to the corresponding backwardly directed secondary wave. The optimum value of θ necessary for high directivity is best obtained from a series of graphs which may be empirically determined by routine experiment, utilizing a directional coupler in which the angle θ is adjustable as described in connection with Figs. 1 and 2.

A reflected primary wave in main guide 10 similarly excites a secondary wave in that auxiliary guide section which extends backwardly with respect to the reflected primary wave. A process of wave selection therefore takes place in the structure here described, for oppositely-directed secondary waves are produced in the auxiliary guide, corresponding to the oppositely-directed incident and reflected primary waves.

Main guide 10 may be a relatively short length of wave guide adapted to be inserted or connected in the transmission line of a microwave system. The manner of operation of the disclosed structure is such that the proportion of energy coupled into the auxiliary guide remains constant and independent of the location along the transmission line at which main guide 10 is connected. The particular value of the standing wave ratio, and the relative phase of the standing wave with respect to the coupling aperture, have no effect upon the proper operation of the directional coupler as outlined above.

In the structure shown schematically in Figs. 1 and 2, the wider walls of the main and auxiliary guides may have various dimensions, correspondingly affecting the optimum value of angle θ. The wider walls of the component wave guides may, for example, be of equal width and greater than 0.707 of the free-space wave length at which the directional coupler is to operate. If desired, the wider walls of the main and auxiliary guides may have unequal widths, both being greater, or one being less and the other greater than the preceding critical dimension. In any one of these instances, however, an angle θ may be selected for which high directivity is achieved in the directional coupler. It is also evident that the main guide may always be made of the same stock wave guide utilized for transmission lines.

Referring now to Fig. 3 of the drawing, an embodiment of the invention is shown in which the angle θ is fixed, and which is adapted to communicate a small fraction of either incident or reflected energy in a transmission line to a utilization apparatus, for example to a frequency meter or other measuring instrument. The reference numeral 10 again designates a length of wave guide which is adapted to be connected in a transmission line of a microwave system. Main guide 10 is here shown provided with flanges 15 and 16 so that it may be joined to a transmission line provided with similar flanges. Other means of providing continuity between a transmission line and a directional coupler may be utilized, however, such as the choke-flange joints shown in the previously mentioned copending application. Associated with main guide 10 is a length of auxiliary guide 11, having closed ends in the illustrated embodiment. A wider wall of auxiliary guide 11 is suitably apertured as indicated at 13, and this wall forms a partition or common wall between the associated wave guides as will be seen. A wider wall of main guide 10 is mortised to receive the apertured wall of auxiliary guide 11 at an optimum angle θ, and the two lengths of wave guide are thus adapted to be interfitted and

secured together as by soldering or other means.

One section of auxiliary guide 11, hereinafter termed the wave-absorbing section, is loaded by a matched termination such as a tapered resistance strip shown at 17, which functions to absorb wave energy propagated toward it. Reflections which would ordinarily otherwise occur are thereby avoided, so that the desired backwardly directed energy in the other section (wave propagating section) of auxiliary guide 11 is not interfered with. A pick-up probe 18 extends into the wave propagating section from a coaxial connector 19, located at a suitable distance from the corresponding end wall, and provides proper matching between the wave propagating section and a coaxial cable, not shown.

The directional coupler structure thus described functions in the manner previously set forth. A primary wave traveling through main guide 10, in the direction indicated by arrow 20 in Fig. 3, excites a proportionately smaller secondary wave in the backwardly extending section of auxiliary guide 11. Energy from the secondary wave is communicated to a utilization apparatus by means of an interconnecting coaxial cable, not shown, which is adapted to be coupled to the backwardly extending or wave-propagating section by means of coaxial connector 19 and pick-up probe 18. Any wave energy which may be excited in the wave absorbing section of the auxiliary guide 11, for example by an oppositely directed primary wave, is prevented by absorbing means 17 from producing disturbing reflections which would interfere with wave energy in the wave propagating section.

The structure shown in Fig. 3 may be modified to have a common wall whose thickness differs from that of the wave guide walls. For example, both the main and auxiliary guides may be mortised and fitted together on opposite sides of an apertured sheet of metal of suitable rhomboidal shape and size, which then functions as the common wall. Electrical continuity may here again be secured as by soldering or other means.

The wave selectivity achieved in the directional coupler of the subject invention is substantially independent of the magnitude and relative phase of standing waves in the transmission line with which it is used. The directional coupler may, therefore, be readily used for measurement of standing wave ratios, for separate measurement of component incident and reflected waves, and in general to provide attenuated coupling to components of a micro-wave system.

It is apparent that the invention is not limited to the physical construction illustrated in the drawing, but that various changes may be made without departing from the spirit of the invention.

What is claimed is:

1. A microwave energy coupler, including a pair of rectangular waveguides interconnected by a common broad wall, said broad wall being formed with a coupling aperture therein, said pair of waveguides being relatively angularly displaced about an axis through said aperture and perpendicular to said common wall at an angle dependent upon the frequency of the microwave

energy, the thickness of said common wall, the size and shape of the coupling aperture and said waveguides dimensions, whereby high directivity is secured.

2. A microwave energy coupler, including a pair of rectangular waveguides interconnected by a common broad wall, said broad wall being formed with a coupling aperture therein, said pair of waveguides being relatively displaced by an angle that is more than zero and less than 90 degrees about an axis through said aperture and perpendicular to said common wall, said angle being determined by the frequency of the microwave energy, the thickness of said common wall the size and shape of the coupling aperture and said waveguides dimensions, whereby high directivity is secured.

3. In a system for directional coupling of microwave energy including a first rectangular waveguide having microwave energy propagated through it in a forward direction, a second rectangular waveguide, said waveguides having their broader walls parallel and contiguous, said walls having aligned apertures therein for coupling energy between said waveguides, said waveguides being rotatable with respect to each other about an axis which passes through said coupling apertures perpendicular to said broader walls and rotatable through an angle between zero and ninety degrees whereby at one position of rotation the energy traveling in a backward direction through said second waveguide is at a maximum and energy traveling in a forward direction in said second waveguide is at a minimum.

4. A microwave energy directional coupler comprising a first rectangular waveguide having an input end and an output end, a second rectangular waveguide positioned at an acute angle with respect to said first waveguide, said first and second waveguides having their broader walls in parallel planes and juxtaposed to form a common wall where they cross, a coupling aperture in said common wall at the vertex of said angle, means to derive an output located in the end of second waveguide which is nearest the input end of said first waveguide, and means to absorb energy located in the end of said second waveguide which is nearest the output end of said first waveguide.

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