July 13, 1965 R. G. VELTROP 3,195,075

VARIABLE DIRECTIONAL COUPLER

Filed Aug. 20, 1962 2 Sheets-Sheet 1

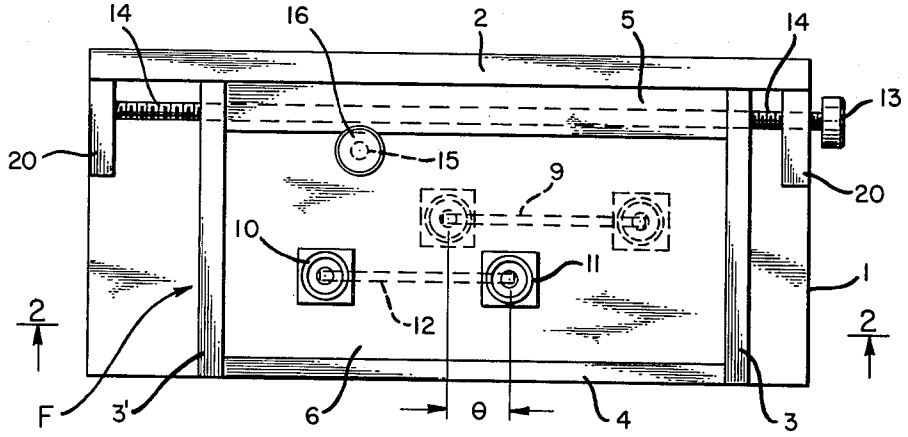


FIG-1

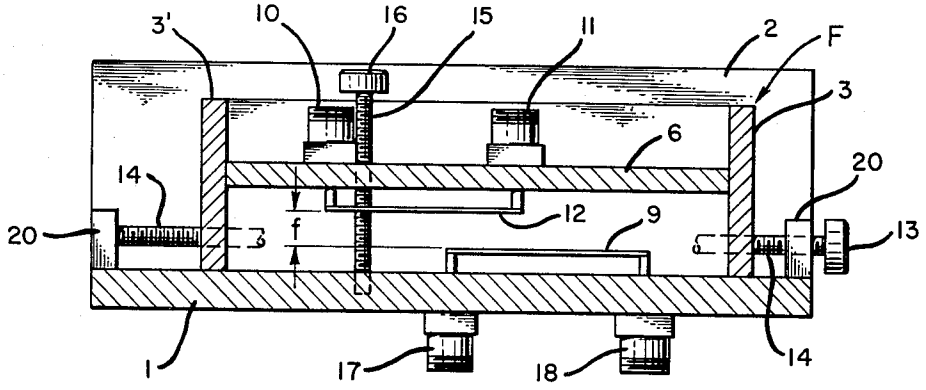


FIG-2

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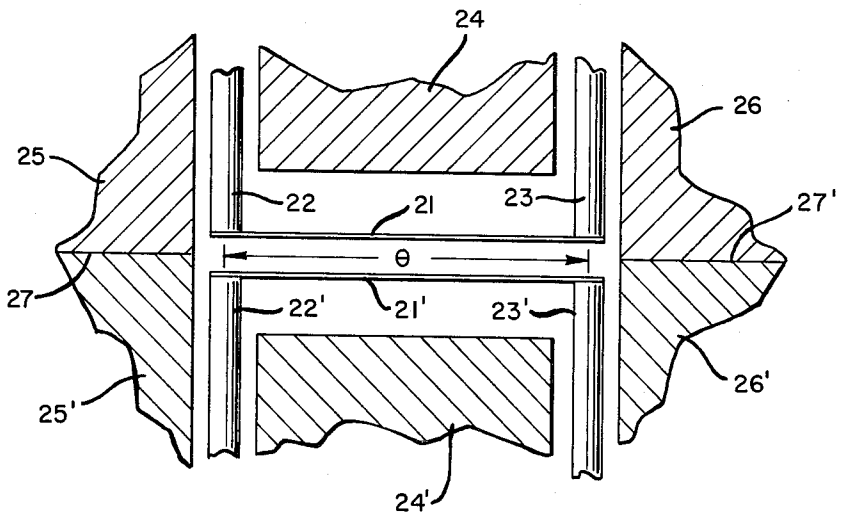


FIG-3

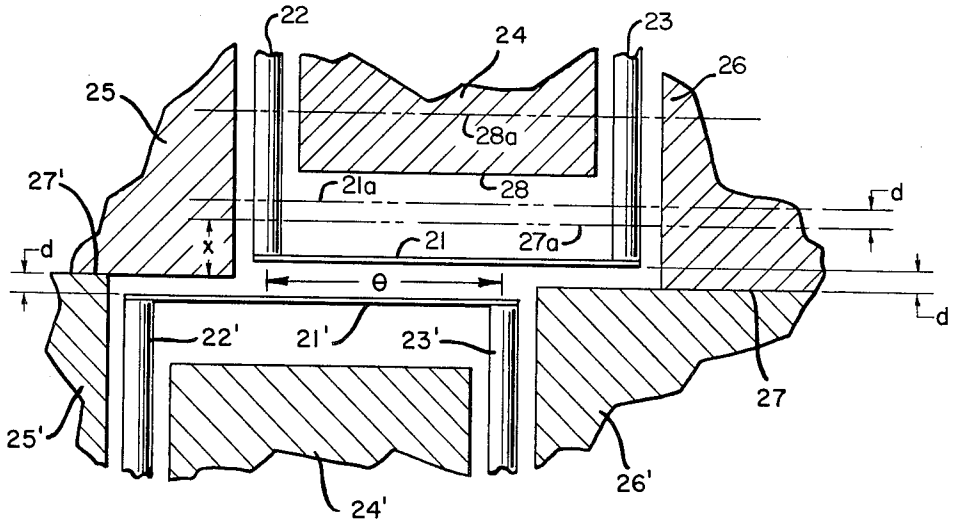


FIG-4

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VARIABLE DIRECTIONAL COUPLER

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1 Claim. (Cl. 333—10)

This invention relates to improvements in variable directional couplers. A general object of this invention is the provision of an electromagnetic directional coupler in which the spatial relationship between two conductors in two orthogonal planes is selectively variable to permit adjustment of the center frequency of the coupling charactertisic as well as the coupling factor.

The invention will be more fully understood from the following detailed description of the operation, reference being made to the accompanying drawings in which:

FIGURE 1 is a plan view of a coupler embodying the invention;

FIGURE 2 is a transverse section taken on lines 2—2 of FIGURE 1;

FIGURE 3 is an enlarged fragmentary sectional view of a modified form of the invention in which the ground planes are relocated in order to increase the bandwidth of the coupler; and

FIGURE 4 is a section similar to FIGURE 3 with the position of the parts shifted to illustrate adjustment of the coupler.

The electromagnetic directional coupler illustrated in FIGURES 1 and 2 comprises a stationary base plate 1 and connected back plate 2 together with a movable frame F consisting of side plates 3 and 3', front plate 4, support plate 5, and upper plate 6. Plates 1, 3, 3', 4, 5 and 6 are electrical ground planes and constitute an outer conducting enclosure. The opposite ends of a primary conductor 12 extend through upper plate 6 and are connected, respectively, to an input line through terminal 10 and to a direct coupled line through terminal 11. The opposite ends of a secondary conductor 9 extend through base plate 1 and are connected, respectively, to a so-called "isolated line" through terminal 17 and to the coupled line through terminal 18. Proximate portions of conductors 9 and 12 are straight and are parallel to each other.

Longitudinal positioning of the movable frame F, FIGURE 1, adjusts the amount of longitudinal overlap of conductors 9 and 12 which overlap constitutes the coupling section having an electrical length θ, and is achieved by rotation of longitudinal drive shaft 14. This drive shaft 14 is threaded through side plates 3 and 3' and support plate 5 and is journalled in supports 20 fixed to base plate 1. Vertical movement of upper plate 6, as viewed in FIGURE 2, adjusts the spacing f between primary and secondary conductors 12 and 9, and is accomplished by threaded shaft 15 journalled in plate 1 and engaging threads in plate 6. Manual adjustment of shafts 14 and 15 is provided by knobs 13 and 16, respectively.

The following explanation of the principle of the operation of a directional coupler will be helpful to an understanding of the invention. Upon connection of an external source of radio frequency energy to input terminal 10, a primary current i_p flows in primary conductor 12. This causes a magnetic field to be set up around the conductor, the direction of the flux lines being clockwise as viewed along the conductor in the direction of current flow. Depending on the proximity of the second conductor to the first conductor, a number of these flux lines link secondary conductor 9 and induce a secondary

voltage v_{si} on the conductor. This is expressed by the relationship

$$v_{si} = -M\frac{di_p}{dt} \tag{1}$$

where M is the mutual inductive coupling between the conductors, and di_p/dt is the rate of change of primary current with time. The negative sign in Equation 1 indicates that the voltage induced on the secondary line opposes the change in the primary current. Thus, when a current i_p flows in conductor 12 from input terminal 10 to output terminal 11, a voltage v_{si} is induced in conductor 9 which causes a current i_{si} to flow in conductor 9 from terminal 18 to terminal 17 when the primary current is increasing in value and from terminal 17 to terminal 18 when the primary current is decreasing in value.

Similarly, currents i_{sc} flow in secondary conductor 9 due to the voltage v_p impressed on conductor 12 by the primary current i_p and the capacitive coupling between the conductors. The currents i_{sc} flow toward the common coupling section (into conductor 9 from terminal 17 and 18) when the primary potential is increasing in value and away from the common coupling section (into terminal 17 and 18 from conductor 9) when the primary potential is decreasing in value.

To summarize, the secondary currents i_{si} and i_{sc} are 180 degrees out of phase in terminal 17 and are in phase in terminal 18 whether the primary current i_p is increasing or decreasing. Therefore, if the coupler is designed such that the inductive and capacitive coupling are equal, the currents flowing in terminal 17 cancel and no output is obtained on the isolated line whereas the currents in terminal 18 add to provide maximum output on the coupled line and yield maximum directivity.

The value of the coupling characteristic, known as the coupling factor, is controlled by changing the value of mutual capacitive and inductive coupling between conductors 9 and 12. This is accomplished without changing the center frequency of the coupler by varying the spacing f between conductors 9 and 12 by means of drive shaft 15 with its knob 16.

The voltages appearing respectively on the coupled line (terminal 18) and on the direct line (terminal 11) are:

$$E_c = \frac{jk \sin\theta E_i}{\sqrt{1-k^2}\cos\theta + j\sin\theta} \tag{2}$$

$$E_d = \frac{\sqrt{1-k^2}E_i}{\sqrt{1-k^2}\cos\theta + j\sin\theta} \tag{3}$$

where k is the voltage coupling coefficient, E_c is the coupled voltage, E_d is the direct or output voltage, E_i is the input voltage, and θ is the electrical length of the common coupling section between conductors 9 and 12. The coupled signal is maximum for $\theta=(2n-1)\pi/2$ radians, $n=1, 2, 3, \ldots$, or when $\sin\theta=\pm 1$. The coupling coefficient, determined by the physical relationship between the conductors and the ground plane, determines the bandwidth of the coupler.

With a known common coupling section of electrical length θ which is $\lambda/4$ long at some frequency it is possible to determine the center frequency of the coupling characteristic and the directional coupler from the relationship

$$\theta = \frac{\lambda}{4} = \frac{1}{4}\frac{c}{f} \tag{4}$$

$$f = \frac{1}{4}\frac{c}{\theta} \tag{5}$$

where f is the center frequency, λ is the wavelength, and

c is the velocity of light. Adjustment of the electrical length θ of the common coupling therefore makes it possible to vary the center frequency of the coupling characteristic.

In the embodiment of FIGURES 1 and 2, the electrical length θ of the common coupling section is varied by rotating knob 13 and shaft 14 to adjust the relative longitudinal displacement of conductors 9 and 12. For coupling values of less than 10 db, the spacing of the conductors from each other and from ground planes is sufficient that vertical movement of the upper plate 6 does not affect the characteristic impedance of the conductors and the coupling characteristic remains substantially constant as the center frequency is varied.

In the modified form of the invention shown in FIGURES 3 and 4, the ground planes of the coupler are relocated to provide broadband operation and to provide a constant coupling characteristic for "tight" couplings. Input and output lines 22 and 23 are connected to primary conductor 21. Ground plane 24 is located between lines 22 and 23. The line designated by reference character 28 is the edge of ground plane 24 adjacent to primary conductor 21. Ground planes 25 and 26 are located adjacent to lines 22 and 23, respectively. Lines 22′ and 23′ are connected to secondary conductor 21′. Ground plane 24′ is located between lines 22′ and 23′. Ground planes 25′ and 26′ are located adjacent to lines 22′ and 23′, respectively. The junctions of ground planes 25, 25′ and 26, 26′ are designated by reference characters 27′ and 27, respectively. The phantom lines 21*a*, 27*a* and 28*a* of FIGURE 4 represent another position to which conductor 21, ground plane junction 27 and edge 28 of ground plane 24, respectively, may be moved in order to change the coupling factor; i.e., to change the "tightness" of the coupling.

The relative positions of the input and output lines, the conductors and the ground planes determine the characteristic impedance and match of the coupler, and these parts are adjusted relative to the conductors and with respect to each other to obtain the proper coupling value. When the coupled conductors 21 and 21′ are longitudinally offset (in a right-left direction as viewed in FIGURE 4) to change the center frequency, the coupling factor and the characteristic impedance and match of the lines remain constant because the effective spacing (in the vertical direction, as viewed in FIGURE 4) of lines, conductors and ground planes are constant. The spacing d between conductor 21′ and ground plane 25 is initially adjusted to provide the desired characteristic impedance and is effective for this purpose when the conductors 21 and 21′ are longitudinally offset as shown in FIGURE 4. The same is true of the spacing between conductor 21 and ground plane 26′.

When the conductors and ground planes are moved to the positions shown by the phantom lines in FIGURE 4, junctions 27 and 27′ are offset by a distance X. The spacing d between conductor 21 (coincident with phantom line 21*a*) and ground plane junction 27*a*(coincident with phantom lines 27*a*) is maintained constant at its initial value in order to maintain proper match and characteristic impedance as the conductors are repositioned to vary the center frequency of the coupling characteristic. Thus, the physical relationship between the ground plane and the conductors is maintained constant and adjustment of the coupling characteristic and the center frequency of the coupling characteristic are independent of each other.

As many modifications of this invention can be made without departing from its true spirit, the scope of this invention is to be determined from the appended claim and not from the specific embodiment described herein.

What is claimed is:

A variable directional coupler for coupling electromagnetic energy at microwave frequencies over a frequency band, said coupler comprising

an electrically conducting base member,

a first conductor supported on and insulated from said base member,

said first conductor having a straight portion of predetermined length spaced from and extending parallel to one side of said base member,

an electrically conducting frame supported on said base member for parallel movement relative thereto and forming an enclosure therewith,

said frame comprising side plates projecting from said one side of the base member and an upper plate having an inner side spaced from said base plate,

a second conductor supported on and insulated from said upper plate,

said second conductor having a straight portion of predetermined length spaced from and extending parallel to said one side of the upper plate and being parallel to and overlying said straight portion of said first conductor in a common plane whereby the straight portions of said first and second conductors are totally enclosed by said enclosure,

means for moving said frame parallel to said base member in a direction parallel to said straight portions of said conductors for changing the length that said straight portions overlie each other while maintaining said straight portions parallel and in the common plane whereby to shift the midband frequency of the band over which the energy is coupled, and

means for moving said second conductor relative to said base plate and said first conductor in a direction normal to the said parallel movement to equally change the spacing between the said first and said second conductors at all points along the said conductors whereby the amount of energy coupled between the conductors is changed.

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