United States Patent

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[54] **DIGITAL ELECTROMAGNETIC WAVE PHASE SHIFTER COMPRISING SWITCHABLE REFLECTIVELY TERMINATED POWER-DIVIDING MEANS**
14 Claims, 3 Drawing Figs.

[52] U.S. Cl. ..... **333/10,** 333/31 R
[51] Int. Cl. **H01p 1/18,** H01p 5/14
[50] Field of Search ..... 333/10, 11, 31, 31 A

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ABSTRACT: A digital phase shifter of the reflection type is disclosed which includes a directional coupler, hybrid network or other power division network with switchable load means coupled to ports of the coupler for effecting changes in reflection coefficients of the network to provide incremental phase shifts or delays in the output wave relative to the input wave. A four-port hybrid network is provided with switchable loads, such as diodes, at some of the ports, and the diodes are controlled by control signals. In one arrangement switchable loads are connected to three of the four ports to provide eight states of phase shift spaced 45° apart. Some other arrangements include more than one hybrid network to provide a greater number of incremental phase shifts.

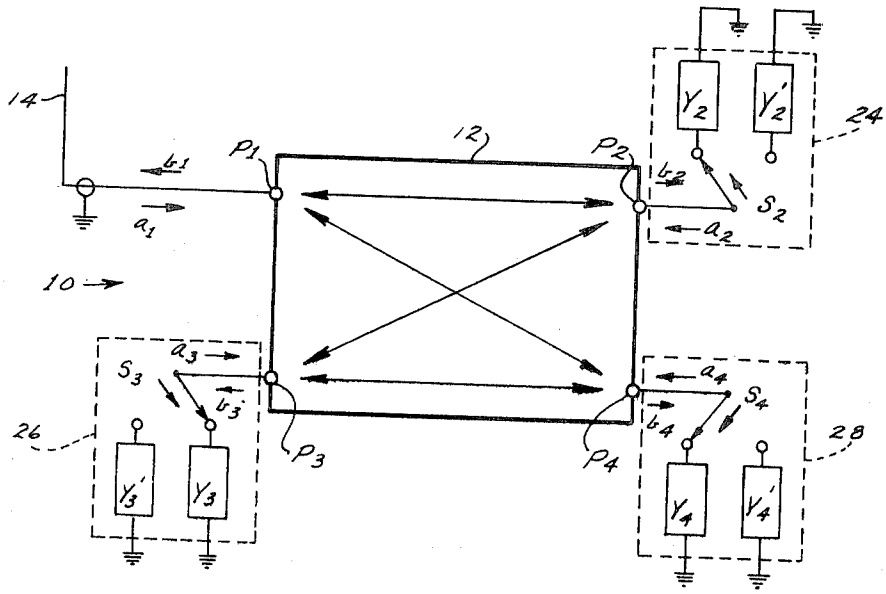
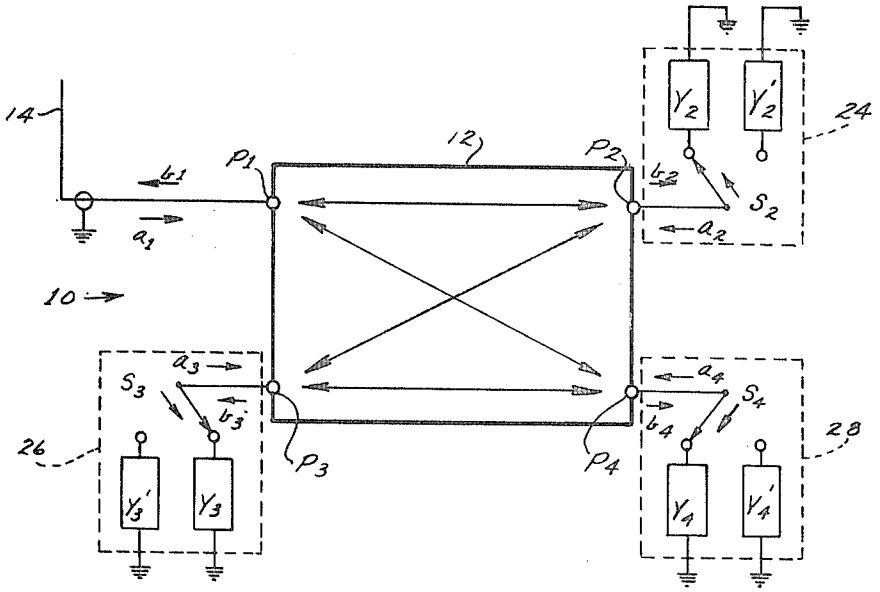


FIG. 1



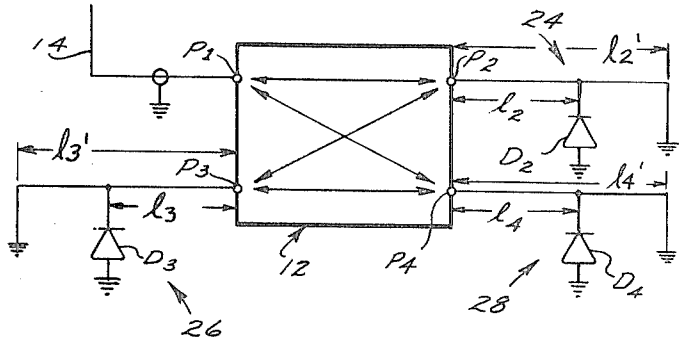


FIG. 2

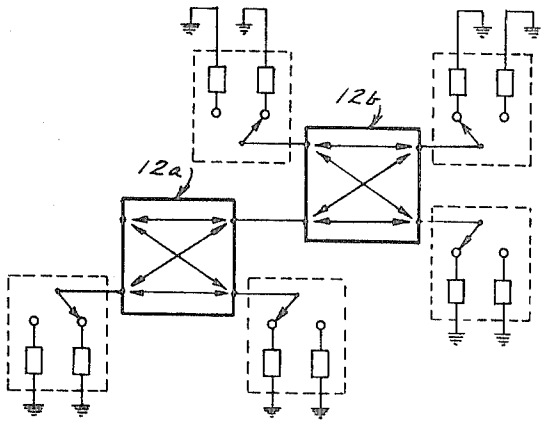


FIG. 3

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DIGITAL ELECTROMAGNETIC WAVE PHASE SHIFTER COMPRISING SWITCHABLE REFLECTIVELY TERMINATED POWER-DIVIDING MEANS

BACKGROUND OF THE INVENTION

This invention relates to electromagnetic wave phase shifters and more particularly to phase shifters of the reflection type.

Electromagnetic wave phase shifters are useful in many types of circuits. In one application, for example, a plurality of digital phase shifters are used to control the direction of radiation of electromagnetic energy in a phased-array antenna application or to control the beam shape. It is, of course, desirable to make shifters that are relatively small, lightweight, require relatively small control power, and are relatively inexpensive, especially where a number of phase shifters are used together, such as in the above-mentioned application. Some phase shifters of prior art required a number of hybrid couplers even where only a relatively few increments of phase shift were required, and this resulted in apparatus which was relatively expensive, great in size and weight, and required relatively large control power.

SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel electromagnetic wave phase shifter of the reflection type.

Another object of the invention is to provide an improved electromagnetic wave phase shifter of the reflection type wherein the above-mentioned undesirable features are substantially obviated.

Another object is to provide a novel phase-shifting network of the reflection type which requires relatively few coefficient of reflection changing means while obtaining a relatively large number of phase shift changes.

Still another object is to provide a phase shifter of the reflection type which utilizes hybrid coupler or other power division means and switchable coefficient of reflection means and which is relatively inexpensive and requires relatively low control power while providing a relatively large number of phase shift changes.

In accordance with one aspect of the present invention, an electromagnetic wave phase shifter is provided which includes a directional coupler having a port for passing input and output waves, and means for effecting a changeable coefficient of reflection at at least some of the other coupler ports to provide at least four different states of phase shift.

These and other objects and advantages of the present invention will be apparent from the foregoing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram of a phase shifter in accordance with an embodiment of the present invention.

FIG. 2 is a schematic diagram illustrating an embodiment of the invention utilizing diodes; and

FIG. 3 is another embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and more particularly to FIG. 1, a phase shifter **10** of the reflection type is shown including a hybrid junction or directional coupler or other power division means **12** having four ports, P_1, P_2, P_3 and P_4. The port P_1 is shown as the input-output port and is connected to a transmission line **14** for accepting an input wave to the phase shifter **10** and accepting the reflected wave from the phase shifter. Ports P_2, P_4 and P_3 may be referred to as the directly-connected port, coupled port, and isolated ports, respectively. Power flow between the ports is in accordance with the flow arrows shown on the coupler **12**.

Connected respectively to the ports P_2, P_3 and P_4 are wave reflection means **24**, **26** and **28** for selectively effecting two different coefficients of reflection at each of the ports. This arrangement provides a total of eight different combinations of reflection coefficients so that an output wave on line **14** will

have any one of eight phase values relative to the input wave on line **14**, the phase values being separated by 45°.

The reflection means **24**, **26** and **28** are illustrated as variable or switchable admittance or impedance networks each shown including a pair of admittances and a switch for selectively connecting the associated port to the admittances. In FIG. **1**, the reflection means **24** is shown including a switch S_2 and admittances Y_2 and Y_2'; the reflection means **26** includes a switch S_3 and admittances Y_3 and Y_3''; and the reflection means **28** includes a switch S_4 and admittances Y_4 and Y_4'.

While the reflection means **24**, **26** and **28** are shown in FIG. **1** as including mechanical switches and admittances, the loading of the ports P_2, P_3 and P_4 can, of course, take on a variety of physical characteristics to yield desired switchable or changeable reflection coefficients. In FIG. **2**, for example, the reflection means **24**, **26** and **28** connected respectively to the ports P_2, P_3 and P_4 of coupler **12** are shown including semiconductor diodes D_2, D_3 and D_4 connected to provide, respectively, two different lengths of line, l_2 and l_2', l_3 and l_3' and l_4 and l_4' to provide different effective impedance values and reflection coefficient phase angles when switched between "on" and "off" states. The diodes, which may be PIN diodes, may be controlled by suitable control signals or bias voltages applied thereto using well-known isolating means between the control signal source and RF circuit. As is well known by those skilled in the art, various other forms of reflection means are possible, such as ferrites and mechanical or electromechanical switches or shutters, the particular form used being dependent, for example, on the frequency under consideration, as well as other criteria.

The desired relative incremental phase shifts (Φ) between the input wave on line **14** and the output wave on line **14** utilizing the four-port directional coupler **12** are obtained by suitably choosing reflection means so as to obtain predetermined reflection coefficients (Γ) and corresponding reflection coefficient angles (θ) at the ports P_2, P_3 and P_4 along with a suitable coupling ratio for the coupler **12**.

In the discussions which follow, numerical subscripts to the various symbols relate respectively to the coupler ports having the same numerical subscripts. Thus, Γ_2, Γ_3 and Γ_4 represent the reflection coefficients at ports P_2, P_3 and P_4, respectively. Since there are two different reflection coefficients at each of the ports P_2, P_3 and P_4, they will be distinguished from each other by using prime symbols; thus, Γ_2 represents herein either of two different reflection coefficients Γ_2' and Γ_2'' at port P_2; Γ_3 represents either of the reflection coefficients Γ_3' and Γ_3'' at P_3; and Γ_4 represents either of the reflection coefficients Γ_4' and Γ_4'' at P_4. Similarly, the reflection coefficient angle θ_2 represents θ_2' or θ_2'' at port P_2; the reflection coefficient angle θ_3 represents θ_3' or θ_3'' at P_3; and reflection coefficient angle θ_4 represents θ_4' or θ_4''.

In defining the values for the six reflection coefficient angles at the coupler ports and the coupling ratio of the coupler **12** to provide the eight possible combinations necessary to obtain the desired eight output phase angles, a scattering matrix approach is used. The scattering matrix for a four-port directional coupler is well known and a detailed discussion of such may be found, for example, in "Microwave Circuit Theory and Analysis," by R. N. Ghose, McGraw-Hill, New York, 1963.

The scattering matrix [S] relates the reflected waves, b, to the incident waves, a, at each of the coupler ports and may be indicated as:

$$[S] = \begin{bmatrix} o & p & o & jq \\ p & o & jq & o \\ o & jq & o & p \\ jq & o & p & o \end{bmatrix} \quad (1)$$

where p and q represent the fraction of the incident voltage at the directly connected and coupled ports and where $p^2+q^2=1$ with p and q being positive real numbers and $\times ab. = 20 \log_{10} q$ is the coupling ratio in db.

Hence, in the present case:

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{bmatrix} o & p & o & jq \\ p & o & jq & o \\ o & jq & o & p \\ jq & o & p & o \end{bmatrix} \begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{vmatrix} \quad (2)$$

a and b, with their respective subscripts, being indicated in FIG. 1.

With power incident at port P_1, each of the other three ports P_2, P_3 and P_4 are loaded with reflection coefficient means so that $\Gamma_2 b_2 = a_2$, $\Gamma_3 b_3 = a_3$ and $\Gamma_4 b_4 = a_4$, therefore:

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{bmatrix} o & p & o & jq \\ p & o & jq & o \\ o & jq & o & p \\ jq & o & p & o \end{bmatrix} \begin{vmatrix} a_1 \\ \Gamma_2 b_2 \\ \Gamma_3 b_3 \\ \Gamma_4 b_4 \end{vmatrix} \quad (3)$$

This matrix equation can readily be solved to obtain a relation between the input wave a_1 and the output wave b_1 by algebraic methods whereby:

$$\frac{b_1}{a_1} = \frac{p^2\Gamma_2 - q^2\Gamma_4 - \Gamma_2\Gamma_3\Gamma_4}{1 + \Gamma_3(q^2\Gamma_2 - p^2\Gamma)} \quad (4)$$

The ratio b_1/a_1 is a complex number, the phase of which is a total phase shift of the device for a particular set of reflection states, Γ_2, Γ_3, and Γ_4. Eight related equations for b_1/a_1 can be written for the phase of the output wave, one corresponding to each of the eight possible combinations of the six reflection coefficient states, Γ_2', Γ_2'', Γ_3', Γ_4' and Γ_4''.

The device is assumed, for purpose of analysis, to be lossless so that the magnitude of the output wave b_1 is equal to the magnitude of the input wave a_1 and the magnitudes of the reflection coefficients are all equal to one. Thus, the ratio of the output wave to the input wave b_1/a_1 can be rewritten in phaser notation as follows:

$$b_1/a_1 = 1 \angle \phi \quad (5)$$

where Φ is the total phase shift of the device and,

(6) $\Phi = \Phi_s + \Phi_i$

where Φ_s is some arbitrary constant starting angle which adds only to the absolute phase shift of the device and Φ_i is the incremental phase shift which is a function of the states of the reflection coefficients.

The reflection coefficients can be written in complex number notation as:

$$\Gamma i = 1 \angle \theta i = \cos \theta i + j \sin \theta i \quad (7)$$

where i=2, 3, or 4 throughout the equation.

The relation between the input and output, equation (4), can now be rewritten in a form which more readily gives a solvable relation for the total phase shift.

Since the magnitudes of the reflection coefficients are one, the complex conjugates can be written as

$$\Gamma i^* = 1/\Gamma i = 1 \angle -\theta i \quad (8)$$

where Γ_i^* is the complex conjugate of Γ_i.

Factoring the produce $-\Gamma_2\Gamma_3\Gamma_4$ out of the relation for b_1/a_1 in equation (4) results in

$$b_1/a_1 = -\Gamma_2\Gamma_3\Gamma_4 \left[\frac{1 + (q^2\Gamma_2 - p^2\Gamma_4^*)\Gamma_3^*}{1 + \Gamma_3(q^2\Gamma_2 - p^2\Gamma_4)} \right] \quad (9)$$

Now factoring Γ_3^* from the numerator and Γ_3 from the denominator one obtains

$$b_1/a_1 = -\Gamma_2\Gamma_3^*\Gamma_4 \left[\frac{\Gamma_3 + (q^2\Gamma_2^* - p^2\Gamma_4^*)}{\Gamma_3^* + (q^2\Gamma_2 - p^2\Gamma_4)} \right] \quad (10)$$

Using the complex notation of equation (7) in the equation (10) and then rationalizing the resulting complex expression, one skilled in the art can arrive at the following equations (11) and (12) and (13) for the phase shift of the device in terms of the phase angles of the reflection coefficients.

$$\phi = \phi s + \phi i = f(X, \theta_2, \theta_3, \theta_4) \quad (11)$$

where

$$f(X, \theta_2, \theta_3, \theta_4) = \pi + \theta_2 + \theta_4 - \theta_3 + 2 \tan^{-1} \left[\frac{\sin\theta_3 - (q^2 \sin\theta_2 - p^2 \sin\theta_4)}{\cos\theta_3 + (q^2 \cos\theta_2 - p^2 \cos\theta_4)} \right] \quad (12)$$

Therefore, the incremental phase shift is defined as follows:

(13) $\Phi_i = f(x, \theta_2, \theta_3, \theta_4) - \Phi_s$

There is, of course, a total of eight equal incremental phase shifts Φ_i spaced 45° apart. The general equation (11), in other words, can be rewritten eight times, each for a different combination of the reflection coefficient angles, the equation (12) defining one of the terms of equations (11), (13). A solution to these eight equations is obtained by choosing values of $X, \Phi_s a[k_2', \theta_2'', \theta_3', \theta_3'', \theta_4'$ and θ_4'', such that the eight equations are simultaneously satisfied, as is shown hereinafter.

By eliminating the arctangent term in equation (12), the desired phase states can be obtained by stepping one reflection coefficient angle 45°, a second 90°, and a third 180°. The arctangent term may be eliminated by forcing the numerator or denominator to zero for all combinations of the reflection coefficient states or by forcing the ratio of the numerator and denominator to retain some constant value for the different reflection coefficient combinations of states.

The way in which this may be accomplished is demonstrated by the following example:

Force the numerator of the arctangent term in the equation (12) to zero.

(14) i.e., $\sin\theta_3 - (q^2 \sin\theta_2 - p^2 \sin\theta_4) = 0$.

Then if the denominator is positive the resulting angle is 0°, and if the denominator is negative, the resulting angle is 2π or, in effect, again 0°,

(15) i.e., 2 tan¹1 (0/+Den)=0° and

(16) 2 tan¹1 (0/−Den)=2x180°=360°

Therefore, the equations for the incremental phase shift can be written:

(17) $\Phi_i = \pi + \theta_2 + \theta_4 - \theta_3 - \Phi_s$

Now the choice can be made of which reflection coefficient will switch the phase 45°, which will switch it 90°, and which will switch it 180°. This choice determines the order in which the incremental phase switches states and also the way in which the numerator is set equal to zero.

To obtain one solution, for example, force θ_3 to switch the phase in 180° steps, θ_2 to switch the phase in 45° steps, and θ_4 to switch the phase in 90° steps.

Therefore:

(18) $\theta_2'' - \theta_2' = 45°$

(19) $\theta_3'' - \theta_3' = -180°$

(20) $\theta_4'' - \theta_4' = 90°$

Now to make the numerator of the arctangent term zero for all states, the following conditions are imposed:

(21) $\sin\theta_3' = 0$

(22) $\sin\theta_3'' = 0$

(23) $g^2 \sin\theta_2' - p^2 \sin\theta_4' = 0$

(24) $g \sin\theta_2'' - p^2 \sin\theta_4' = 0$

(25) $g^2 \sin\theta_2' - p^2 \sin\theta_4'' = 0$

(26) $g^2 \sin\theta_2'' - p^2 \sin\theta_4'' = 0$

The eight equations for the incremental phase shifts, therefore, become:

(27) $\theta_i = \pi + \theta_2' + \theta_4' - \theta_3' - \Phi_s = 0°$

(28) $\theta_i = \pi + \theta_2'' + \theta_4' - \theta_3' - \Phi_s = 45°$

(29) $\theta_i = \pi + \theta_2' + \theta_4'' - \theta_3' - \Phi_s = 90°$

(30) $\theta_i = \pi + \theta_2'' + \theta_4'' - \theta_3' - \Phi_s = 135°$

(31) $\theta_i = \pi + \theta_2' + \theta_4' - \theta_3'' - \Phi_s = 180°$

(32) $\theta_i = \pi + \theta_2'' + \theta_4'' - \theta_3'' - \Phi_s = 225°$

(33) $\theta_i = \pi + \theta_2' + \theta_4' - \theta_3'' - \Phi_s = 270°$

(34) $\theta_i = \pi + \theta_2'' + \theta_4'' - \theta_3'' - \Phi_s = 315°$

The first equation fixes the value of Φ_s to its desired value and the remaining equations follow from the switching conditions imposed above.

The specific switching angles and coupling coefficients are now determined using the equations (18), (19) and (20) and the imposed conditions which force the numerator of the arctangent phase term to zero for all states. Hence, (35) $\sin \theta_3' = \sin \theta_3'' = 0$

(36) $\theta_3'' - \theta_3' = -180°$.

(37) Therefore, $\theta_3' = 0$

(38) $\theta_3'' = -180°$.

Also, (39) $q^2 \sin \theta_2' - p^2 \sin \theta_4' = 0$

(40) $q^2 \sin \theta_2'' - p_2 \sin \theta_4' = 0$

(41) $q^2 \sin \theta_2' - p^2 \sin \theta_4'' = 0$

(42) $q^2 \sin \theta_2'' - p^2 \sin \theta_4'' = 0$

(43) $\theta_2'' - \theta_2' = 45°$

(44) $\theta_4'' - \theta_4' = 90°$

Subtracting equation (39) from (40) results in

$$q^2 \sin \theta_2'' - q^2 \sin \theta_2^1 = 0 \quad (45)$$

$$0 = \sin(\theta_2^1 + 45°) - \sin \theta_2^1 \quad (46)$$

$$\sin(\theta_2^1 + 45°) = \sin \theta_2^1 \cos 45° + \cos \theta_2^1 \sin 45°$$

$$= \frac{\sqrt{2}}{2}(\sin \theta_2^1 + \cos \theta_2^1) \quad (47)$$

so

$$\frac{\sqrt{2}}{2} \cos \theta_2^1 = \left(1 - \frac{\sqrt{2}}{2}\right) \sin \theta_2^1 \quad (48)$$

therefore

$$\tan \theta_2^1 = \frac{\frac{\sqrt{2}}{2}}{1 - \frac{\sqrt{2}}{2}} = \frac{1}{\sqrt{2} - 1} \quad (49)$$

Subtracting equation (39) from (41)

(50) $p^2 \sin \theta_4' - p^2 \sin \theta_4'' = 0$ on

(51) $0 = \sin \theta_4' - \sin(\theta_4' + 90)$ But

(52) $(\theta_4' + 90°) = \sin \theta_4' \cos 90° + \cos \theta_4' \sin 90° = \cos \theta_4'$

(53) so $\sin \theta_4' = \cos \theta_4'$ therefore

(54) $\tan \theta_4' = 1$

Values of θ_2' and θ_4' which satisfy the above tangent equations are: (55) $\theta_2' = 67.5°$

(56) $\theta_4' = 45°$

Using these values, the coupling ratio x can be determined from equation (39)

(57) $q^2 \sin 67.5° - p^2 \sin 45° = 0$ or

(58) $q^2(0.924) - p^2(0.707) = 0$

Recalling that $q^2 + p^2 = 1$

(59) $q^2(0.924) - (1 - q^2)(0.707) = 0$ *So*

(60) $q^2 = 0.433$

(61) $p^2 = 0.567$

(62) $X db. = -10 \log_{10} q^2 = -10 \log_{10} 0.433$

(63) $X db. = 3.63 db.$ and

(55) $\theta_2'' = 67.5°$

(64) $\theta_2'' = 112.5°$

(56 $\theta_4' = 45°$

(65) $\theta_4'' = 135°$

The value of s is then obtained from the first of the eight equations for the incremental phase. (66) $\Phi_f = 0° = \pi + \theta_2' \theta_4' - \theta_3' - \Phi_s$ so

(67) $\Phi_s = -0° + 180° + 67.5° + 45° - 0°$ or

(68) $\Phi_s = 292.5°$

In conclusion, therefore, the desired parameters for this particular design are:

$$X = 3.63 db \quad (63)$$

$$\phi s = 292.5° \quad (68)$$

$$\theta_2' = 67.5° \quad \text{or} \quad \Gamma_2' = 1 \angle 67.5° \quad (55)$$

$$\theta_2'' = 112.5° \quad \text{or} \quad \Gamma_2'' = 1 \angle 112.5° \quad (64)$$

$$\theta_3' = 0° \quad \text{or} \quad \Gamma_3^1 = 1 \angle 0° \quad (37)$$

$$\theta_3'' = -180° \quad \text{or} \quad \Gamma_3'' = 1 \angle -180° \quad (38)$$

$$\theta_4' = 45° \quad \text{or} \quad \Gamma_4' = 1 \angle 45° \quad (56)$$

$$\theta_4'' = 135° \quad \text{or} \quad \Gamma_4'' = 1 \angle 135° \quad (65)$$

The values for Φi as indicated above are readily verified by substituting the eight possible combinations of the reflection coefficients into the design equation (4) and rationalizing the resulting complex expression.

In the illustrated embodiments of FIGS. 1 and 2, three-bit phase shifter arrangements are shown in which the output wave can be switched to provide as many as eight incremental steps or phase states as indicated by equations (27) through (34). However, phase shifters can be provided that afford other than eight steps of phase shift. In FIG. 3, for example, there is illustrated a phase shifter arrangement wherein a directional coupler 12*a* has its directly connected port connected to an input port of another directional coupler 12*b*. Any of the ports of coupler 12*a* can be used for this configuration. By switchable choices of coupling coefficients and reflection means, the phase shifter arrangement of FIG. 3 can provide up to a total of 32 phase states of equal increments, it being shown as a five-bit arrangement having a total of five switchable reflection means, each having two states. This arrangement can be extended to more than two couplers with additional cascading to increase the number of phase states possible. This technique can be applied to stripline, microstrip, waveguide, coaxial line or any other transmission media.

As various changes could be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Electromagnetic wave phase shifting means comprising a directional coupler having first port means for passing input and output electromagnetic waves, and at least three other ports, and electromagnetic wave reflective means coupled to each of said other ports, said reflective means each being selectively changeable to effect at least two different reflection coefficients thereby providing any of at least eight output wave phase states.

2. The phase-shifting means according to claim 1 wherein one of said wave-reflective means comprises power-dividing means having a plurality of ports, and other switchable reflective means respectively coupled to said last-named ports.

3. The phase-shifting means according to claim 1 wherein each of said reflective means includes switchable load means to effect either of two different reflection coefficient angles at their respective ports.

4. The phase-shifting means according to claim 3 wherein each of said reflective means includes switch means and predetermined impedance means.

5. The phase-shifting means according to claim 3 wherein each of said reflective means includes transmission line means, switch means coupled to said line means to provide a predetermined length of said line at the associated port when the switch means is closed and to provide another predetermined length of said line when said switch means is open, and means for selectively switching said switch means between its closed and open states.

6. The phase-shifting means according to claim 5 wherein each of said switch means comprises a diode.

7. Electromagnetic wave phase shifting means of the reflection type comprising power-dividing means including first-port means for passing input and output electromagnetic waves, and exactly three other ports, three wave-reflective means including respectively three impedance means coupled respectively to said three ports, each of said impedance means having exactly two impedance values, three switch means respectively connected to said impedance means for switching its associated impedance means from one of its values to the

other, said wave-reflective means being individually selectively operable to provide any one of eight phase shifts of said output wave.

8. The phase-shifting means according to claim 7 wherein each of said switch means comprises a solid-state diode, and control signal means for controlling the conductivity of the diode.

9. The phase-shifting means according to claim 7 wherein said power-dividing means comprises directional coupler means, each of said reflective means including switchable load means to effect either of two different reflection coefficient angles at its respective port.

10. An electromagnetic wave phase shifting means of the reflection type comprising a directional coupler having at least four ports including first-port means for passing input-incident and output-reflective waves, and second, third and fourth ports, said second port being directly connected to said first port, said third port being isolated with respect to said first port, and said fourth port being coupled with respect to said first port, whereby incident power flowing into said first port flows directly to said second and fourth ports, and said third port receives power substantially only from said second and fourth ports; first, second and third switchable wave-reflective means coupled to said second, third and fourth ports, respectively, each of said reflective means having at least two states providing at least two reflection coefficient angles at the port coupled thereto, and means for individually selectively switching said reflective means to selectively provide at least five different combinations of reflection coefficient angles at said second, third and fourth ports to selectively permit any one of at least five phase shifts of the output-reflective wave at said first port, the ratio of the power division between said second and fourth ports and the relative values of said reflection coefficients being chosen to provide output wave phase shifts in substantially angularly equal incremental steps.

11. The phase-shifting means according to claim 10 wherein each of said reflective means includes reactance means switchable between two reactance values.

12. The phase-shifting means according to claim 10 wherein each of said reflective means includes a diode and two different lengths of transmission line.

13. The phase-shifting means according to claim 10 wherein the ratio of the power division between said second and fourth ports is chosen to provide a coupling ratio substantially less than 3db.

14. The phase-shifting means according to claim 13 wherein each of said reflective means has exactly two states providing exactly two reflection coefficient angles at the port coupled thereto and wherein the ratio of the power division between said second and fourth ports and the relative values of said reflection coefficients are chosen to provide output wave phase shifts in eight substantially angularly equal incremental steps.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,611,199 Dated October 5, 1971

Inventor(s) Paul Safran

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 76, cancel "xab = 20" and insert ---Xdb = -20---;

Column 3, lines 2-10, after "a^1, a^2, a^3, a^4" insert a vertical line; lines 16-23, cancel "

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{bmatrix} o & p & o & jq \\ p & o & jq & o \\ o & jq & o & p \\ jq & o & p & o \end{bmatrix} \begin{matrix} a_1 \\ \Gamma_2 b_2 \\ \Gamma_3 b_3 \\ \Gamma_4 b_4 \end{matrix}$$

" and insert ---

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{bmatrix} o & p & o & jq \\ p & o & jq & o \\ o & jq & o & p \\ jq & o & p & o \end{bmatrix} \begin{matrix} a_1 \\ \Gamma_2 b_2 \\ \Gamma_3 b_3 \\ \Gamma_4 b_4 \end{matrix}$$

---;

line 28 (the divisor of the equation numbered (4)), change "$p^2\Gamma$" to ---$p^2\Gamma_4$---; line 35, after "Γ_3'," insert ---Γ_3",---; line 63, cancel "produce" and insert ---product---;

Column 4, line 9 (divisor of equation (12)), cancel "g^2" and insert ---q^2---; lines 8 and 9, after the equation, close the bracket; line 20, after "ϕ_s" cancel "a[k_2'" and insert ---θ_2'---; lines 38 and 39 (equations 15 and 16), cancel "$\tan^1$" (both occurences) and insert ---$\tan^{-1}$---; line 59, change "g^2" to ---q^2---; line 60, change "g" to ---q^2---; line 61, change "g^2" to ---q^2---; line 62, change "g^2" to ---q^2---; line 70 (equation (32)), change "θ_4"" to ---θ_4'---;

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,611,199 Dated October 5, 1971

Inventor(s) Paul Safran

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, lines 16-33 (equations (45)-(49), in each instance, change "$\theta_2{}^1$" to ---θ_2'---; line 35, cancel "on" and insert ---or---; line 54, change "θ_2" = 67.5°" to ---θ_2' = 67.5°---; line 60 (equation (66)), after "θ_2'", insert --- + ---; line 75 (equation (37)), cancel "$\Gamma_3{}^1$" and insert ---Γ_3'---;

Claims 2, 3, 4, 5, 6, 8, 9, 11, 12, 13 and 14, omit the hyphen between "phase" and "shifting".

Signed and sealed this 15th day of August 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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