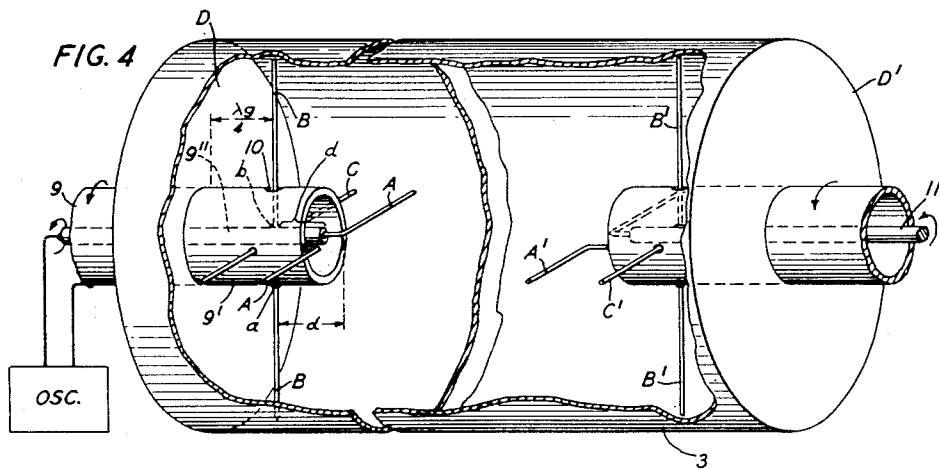
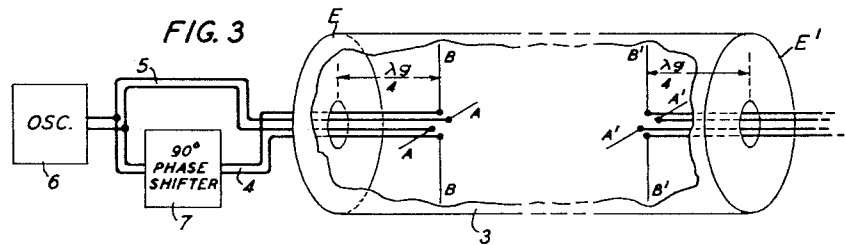
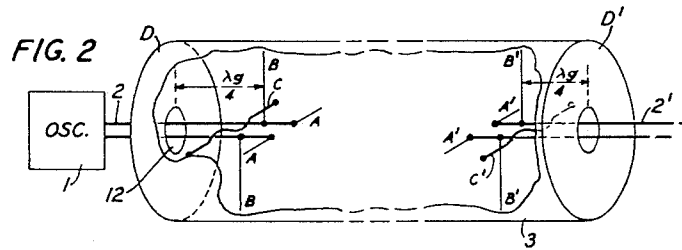
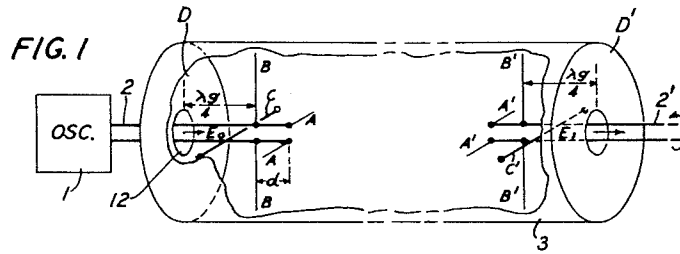


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VARIABLE PHASE SHIFTER FOR CIRCULARLY
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VARIABLE PHASE SHIFTER FOR CIRCULARLY POLARIZED MICROWAVES

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This invention relates to microwave transmission systems, and more particularly, to variable phase shifters associated with wave guides.

A principal object of the invention is the provision of a wave guide phase shifter having a rotating electromagnetic field established therein, whereby the phase characteristic of propagated electromagnetic waves may be adjusted by rotation.

An object of the invention is the provision of a wave guide phase shifter utilizing circularly polarized waves for producing phase change.

Another object of the invention is to variably change the phase of a circularly polarized wave propagated in a wave guide in accordance with angle of rotation.

The term "dominant wave" used herein refers to a characteristic wave mode, having the lowest possible cut-off frequency, capable of propagation in a predetermined wave guide.

"Linear polarization" as used herein is defined as the state of the electromagnetic field, wherein the electric field vectors are characterized by fixed directions.

"Circular polarization" is defined herein, as the state of the electromagnetic field, wherein the electric field vectors are resolvable into mutually perpendicular, linearly polarized components of equal amplitude, differing 90 degrees in time phase. Circularly polarized waves may be considered as the special form of elliptically polarized waves, described in the United States Patent 2,257,783 issued October 7, 1941 to A. E. Bowen, wherein the orthogonal components are equal in amplitude.

In accordance with a specific embodiment of the invention, the variable phase shifter is interposed in a transmission line of the Lecher wire or concentric line type, and comprises a section of wave guide, having sets of mutually perpendicular, dipole antennas spaced apart therein and connected to portions of the transmission line between which the wave guide section is interposed. Electromagnetic waves are first converted into a circular polarization at one dipole set, and then shifted in phase by rotating one set with respect to the other.

In the drawings:

Fig. 1 shows schematically one form of the invention;

Fig. 2 shows a modification;

Fig. 3 shows a modification, wherein the dipoles are coplanar, and

Fig. 4 shows another modification for use with coaxial lines.

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Referring to Fig. 1, a conventional oscillator 1 of ultra-high frequency or microwaves is coupled to a Lecher wire transmission line 2, 2'.

In order to introduce a desired phase shift in the output wave E_1 , a phase shifter comprising a section of circular wave guide 3 is interposed in the line, of diameter and length sufficient to permit the free propagation of circularly polarized waves of the dominant type therein. A set or pair of mutually perpendicular dipoles AA, BB is located in the wave guide section near one end thereof and connected to the line 2 for the purpose of converting the input waves into a circularly polarized state and then launching the circularly polarized waves into the guide section 3. A similar set of receiving dipoles A'A', B'B' is located at the opposite end of the guide 3, and rotated to produce a phase shift in the output wave E_1 , propagated along the Lecher line 2'.

The structures illustrated in Figs. 1 and 2 are essentially alike; the principal difference therebetween being in the disposition of the plane containing the Lecher wires.

The Lecher wires 2 which may be disposed either in a vertical or horizontal plane (Figs. 1 and 2) enter the guide section 3 through an opening 12 in the end wall D of the guide 3. Launching dipole BB is bridged across line 2 and is disposed parallel to the plane of the wall D, and spaced a distance

$$\frac{\lambda_g}{4}$$

therefrom. The other dipole AA, which is identical in structure and proportions to dipole BB, is connected to the terminus of line 2 and disposed perpendicularly to the direction of dipole BB. The spacing between the perpendicularly disposed dipoles measured along line 2 should be

$$d = \frac{\lambda_g \lambda_{\text{conc.}}}{4(\lambda_g - \lambda_{\text{conc.}})} \quad (1)$$

where

λ_g equals the wavelength in the guide,
 $\lambda_{\text{conc.}}$ equals the wavelength on the Lecher wires or alternatively on the equivalent concentric line.

Essentially, distance d constitutes an equivalent 90-degree difference in time phase for waves radiated into the guide from dipoles AA and BB, respectively, and is derived from the relationship

$$\frac{d}{\lambda_g} - \frac{d}{\lambda_{\text{conc.}}} = \frac{1}{4} \text{ cycle} \quad (2)$$

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In other words, a wave launched from dipole BB into the guide 3 completes

$$\frac{d}{\lambda_r}$$

cycles therein, while the corresponding in-phase wave traveling along the Lecher line 2 to dipole AA completes

$$\frac{d}{\lambda_{\text{conc.}}} \text{ cycles}$$

Accordingly, at the position of dipole AA, a time phase difference of

$$\left(\frac{d}{\lambda_r} - \frac{d}{\lambda_{\text{conc.}}} \right) \text{ cycles}$$

has developed between these waves, which difference is maintained constant therebeyond in the propagation of these waves through the guide toward the receiving dipoles A'A', B'B'. In order this time phase difference may amount to 90 electrical degrees, whereby the waves may be in time quadrature relationship to each other, the distance d is so chosen that

$$\frac{d}{\lambda_r} - \frac{d}{\lambda_{\text{conc.}}} = \frac{1}{4} \text{ cycle}$$

as previously defined in Equation 2.

In summary, input waves E_0 traveling along the Lecher wire transmission line 2 are converted by the mutually perpendicular dipoles AA, BB into circularly polarized waves, which are launched into and propagated through the wave guide section 3. The circularly polarized waves are characterized by component waves E_A , E_B equal in amplitude and parallel respectively to the dipoles AA and BB, i. e. the components E_A , E_B are in space and time quadrature relationship to each other.

The wave guide section 3 may be a circular pipe as disclosed in United States Patent 2,129,712 issued September 13, 1938, to G. C. Southworth or any other well-known microwave guide structure of suitable cross-section.

Waves directed rearwardly from the dipoles BB, AA are respectively reflected by the reflecting end wall D and the reflector C with such phase as to reinforce the launched circularly polarized waves. The reflector C is spaced a distance

$$\frac{\lambda_r}{4}$$

from dipole AA to which it is parallel. It may be passed directly (Fig. 1) or by looping (Fig. 2) between the Lecher wires 2, out of contact therewith and may be fastened to the guide section 3 at opposing points thereof, or alternatively, to a bridging insulator bead interposed between the Lecher wires 2. The end wall D is correspondingly spaced a distance

$$\frac{\lambda}{4}$$

from dipole BB.

Impedance matching between the launching dipoles AA, BB and the wave guide section 3 may be achieved by the proper choice of length and cross-sectional configuration for the dipoles, or by means of conventional matching circuits interposed in the line 2. The length of the dipole arms will essentially determine a resistance parameter, while the cross-sectional dimension and configuration will provide a reactive parameter utilizable for impedance match. Experimental manipulation of these parameters until standing wave ratios are reduced to substantially zero will

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determine the existence of a matched condition. Alternatively, the impedance matching circuits, which may be interposed in the line 2, may assume the form of the conventional

$$\frac{\lambda}{4}$$

impedance transformer, or tapered sections of coaxial line known to the prior art. Essentially a free flow of energy with impedance matching throughout the system is desired.

The circularly polarized waves launched into the guide 3 are propagated therein and picked up by the receiving dipole set A'A', B'B', identical to the corresponding radiating dipoles in structure, proportioning and spacing. The reflecting end wall B' and the reflector C' correspond to and are identical to their counterparts D and C.

Each receiving dipole A'A' and B'B' is energized by the component (E_A , E_B) of the circularly polarized wave parallel thereto, respectively. Phase coincidence between these components is established in the resultant output wave E_1 , as a result of the spacing d between dipoles A'A' and B'B', which serves to introduce another 90-degree phase displacement.

The resultant output wave E_1 propagated on the Lecher line 2' may have its phase varied by rotating the receiving dipole set A'A', B'B' by some mechanical means (not shown) relative to the launching set.

It may be desirable to shift the phase of the circularly polarized wave in the guide 3, whereupon launching dipoles AA, BB may be rotated.

In the modification shown in Fig. 3, dipoles AA and BB are in space quadrature and coplanar. Energization thereof from a common oscillator 6 is produced by means of a transmission line, which branches into two parallel lines 4 and 5, respectively. Time quadrature in the components E_A , E_B radiated from dipoles AA and BB, respectively, is produced by the interposition of a conventional 90-degree phase shifter in transmission line 4.

Accordingly, with space and time quadrature established for these components, a circularly polarized wave will be propagated through the guide section 3 and will be received by dipoles A'A', B'B' at the opposite end of the wave guide 3. A phase shift in the circularly polarized wave may be introduced by relative rotation between the respective dipole sets.

The launching dipole set AA, BB is spaced a distance

$$\frac{\lambda_r}{4}$$

from the end wall D of the guide section, in order that rearwardly directed wave energy may be reflected by D in aiding phase with the forwardly radiated wave. Similarly, the dipole set A'A', B'B' is spaced a

$$\frac{\lambda_r}{4}$$

distance from end wall D', to cause waves reflected by D' to reinforce the waves received at A'A', B'B'.

The form shown in Fig. 4 is substantially identical in structure and operation to that illustrated in Fig. 1, except for the substitution of concentric lines 9, 11 for the corresponding Lecher wires 2, 2'.

High frequency or microwave input oscillations are applied by the oscillator to the concentric

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line 9, consisting of an inner and outer cylindrical conductor 9' and 9'', respectively. The dipole AA of the launching set is connected to the inner and outer conductor, respectively, as shown in Fig. 4. Dipole BB is bridged across the concentric line 9 and disposed parallel to the end wall D thereof and perpendicular to dipole AA. One arm thereof is fastened to the outer conductor 9' at point a, while the other arm thereof extends through aperture 10 to fasten to the inner conductor 9'' at point b.

Space and time quadrature between the radiated components E_A , E_B results from the mutual perpendicularity of dipoles AA and BB and from the spacing d aforementioned therebetween. Hence, a circularly polarized wave will be launched into and propagated through guide section 3.

The reflector C and the end wall D are spaced with respect to the dipoles in the manner described in connection with Fig. 1. Reflector C which is parallel to and coextensive with dipole AA is fastened to the outer conductor 9'' of the concentric line. At the receiving end, the reflecting end wall D' and the reflector C' correspond to C and D both in structure and function.

The circularly polarized wave propagated through the wave guide section 3 is picked up at the other end by the receiving dipoles A'A', B'B'. Quadrature components E_A , E_B are brought into phase coincidence by means of the path difference or spacing d between the receiving dipoles. The resultant output wave is then transmitted along the concentric line 9'.

Rotation of the receiving dipole set A'A', B'B' may be produced by rotating the concentric line 11 to produce a relative phase displacement in the output wave, proportional to the angle of rotation. Rotation of the launching dipole set AA, BB will effect a shift in phase of the circularly polarized wave propagated in the guide section 3.

Reflectors C, D and C', D' perform the same functions as described previously for the structure of Fig. 1.

For the principal purposes of this invention, circularly polarized waves are to be preferred, inasmuch as thereby phase change may be produced without concomitant alteration in amplitude. On the other hand, elliptically polarized waves may also be utilized within the compass of the invention under circumstances where constant output amplitude is not an essential requirement of performance.

Whereas the novel phase shifter has been disclosed in connection with wave guides for which it is particularly suited and useful, it should be understood that the structure and principles involved therein, could likewise be applied to the phase shifting of waves propagated in free space or in other homogeneous transmission media.

What is claimed is:

1. A phase shifter for microwaves comprising a pair of mutually perpendicular dipoles, spaced

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apart by 90 electrical degrees at the operating wavelength to radiate circularly polarized waves, a pair of mutually perpendicular dipoles spaced apart by 90 electrical degrees at the operating wavelength for receiving said waves, a conductive enclosure having a principal axis and extending therebetween for confining and guiding said circularly polarized waves, and means for rotating one pair about said axis and relative to the other pair, whereby the phase of the received waves may be adjusted a predetermined amount.

2. In combination, separate pairs of mutually perpendicular antennae, means for producing a time quadrature relationship in the polarized waves radiated from one pair, whereby circularly polarized waves are launched therefrom, a cylindrical wave guide having a high frequency cut-off adapted to propagate and guide said waves between said pairs of antennae, the axis of said wave guide being perpendicular to said pairs, and means for rotating one pair as a unit relative to the other pair whereby the phase characteristics of said waves may be varied.

3. A phase shifter connected between transmission lines, comprising a section of wave guide connected to said lines for coupling them for wave energy transfer, mutually perpendicular antennae spaced along one of said transmission lines a distance corresponding to 90 electrical degrees at the operating wavelength to radiate circularly polarized waves, dipoles connected to the other line for receiving said waves, and means for rotating said dipoles as a unit relative to the antennae for varying the phase characteristic, said wave guide enclosing said antennae and provided with reflecting end walls spaced a distance

$$\frac{\lambda_g}{4}$$

from one thereof, wherein λ_g is the wavelength in the guide.

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