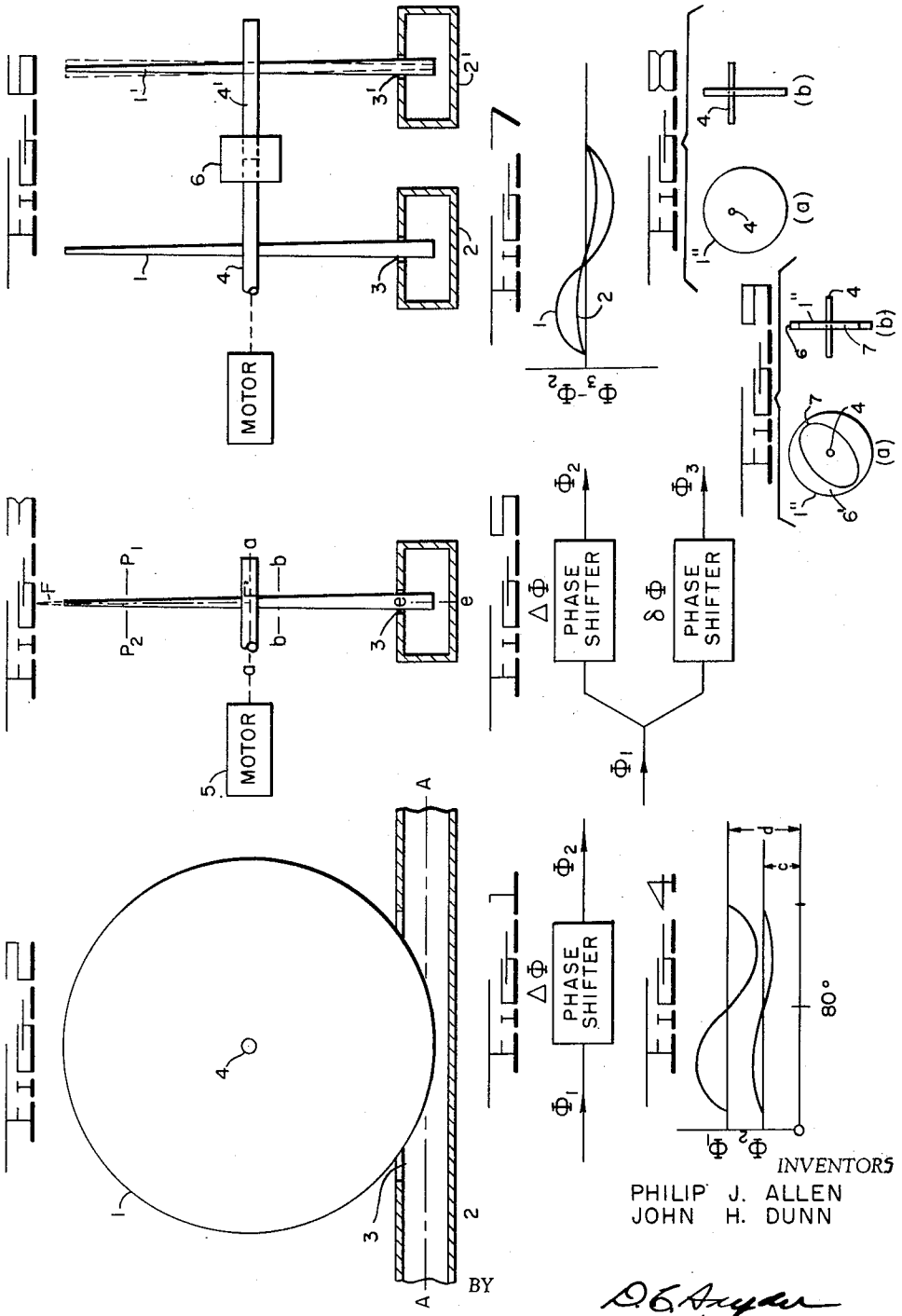
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DIELECTRIC DISC PHASE-SHIFTER FOR WAVEGUIDE

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DIELECTRIC DISC PHASE-SHIFTER FOR WAVEGUIDE

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This invention relates to phase shifting apparatus for use in high frequency transmission systems utilizing hollow waveguides as the transmission means.

More particularly, the present invention relates to phase shifting apparatus for use in hollow waveguides where the degree of phase shift may be simply and quickly varied.

It is known in the prior art that varying the dielectric constant of the medium in which an electromagnetic wave is travelling will vary the velocity of propagation of the wave travelling therein. This change in velocity causes a change in phase of the wave.

Hollow waveguides are utilized as a conduit for electromagnetic energy and placing a piece of low-loss dielectric material within a waveguide will shift the phase of the waves travelling therein for the reasons just described.

The present invention utilizes a low-loss dielectric material to vary the phase shift of the electromagnetic waves within a hollow waveguide in a novel and expeditious way. In one embodiment of the present invention, a plate made of a low-loss dielectric material having non-uniform dimensions is rotatably mounted adjacent a hollow waveguide and caused to protrude through a slot in the walls of the waveguide. Revolving the dielectric plate about its axis causes different amounts of dielectric material to protrude into the waveguide providing a single and convenient control for varying the phase shift of the energy within the waveguide.

In another embodiment of the present invention a plate having areas of varying dielectric constant is rotatably mounted adjacent a hollow waveguide and caused to protrude through a slot in the walls of the waveguide. Rotating the dielectric plate about its axis will cause the dielectric constant of the material protruding into the waveguide to vary thereby causing a change in phase shift of the energy within the waveguide.

The present invention has its greatest utility when it is desired to continuously vary the apparent phase of the energy within a waveguide at a high rate such as required in directional antenna beam scanning problems where the beam shift is obtained by varying the phase of the energy fed to the antenna elements. By driving the dielectric plate at a high rate of speed, the phase shift of the waveguide energy is quickly varied with ease and simplicity. This was not readily possible with the cumbersome prior art phase shifting devices.

The present invention also makes it possible to simply cause the degree of phase shift to follow a sine wave function. By shaping the dielectric plate in the form of a circular disc and then tapering the cross section of the plate so that the thickness linearly varies from one edge of the plate to the diametrically opposite end, a substantially sinusoidal phase shifting variation is simply obtained.

Accordingly one object of the present invention is to provide a novel and simple phase shifting device for use in hollow waveguide systems.

Another object of the present invention is to provide a novel and simple phase shifting device for use in hollow waveguide systems for quickly and continuously varying the phase shift of the energy within the waveguide.

Still another object of the present invention is to provide a novel and simple phase shifting device for use in hollow waveguide systems for causing a continuous sinusoidal variation in phase shift.

A further object of the present invention is to provide a phase shifting device for use in waveguides where no substantial impedance mismatch results.

These and other objects of the present invention will become apparent from the specification and drawings wherein:

Figure 1 is a block diagram representing one embodiment of the present invention.

Figure 2 is a front view of one practical embodiment of the present invention.

Figure 3 is a side view of the embodiment of Figure 2.

Figure 4 is a curve showing the phase shift as the dielectric plate or wheel is rotated for two positions of the axis of the dielectric plate or wheel.

Figure 5 is a block diagram representation of another embodiment of the present invention.

Figure 6 is a side view of the variant embodiment illustrated in block form in Figure 5.

Figure 7 is a curve showing the phase shift as the dielectric plates are rotated for two relative positions of the plates.

Figure 8(*a*) and (*b*) is a front and side view of an alternative form of dielectric plate.

Figure 9(*a*) and (*b*) is a front and side view of another form of the dielectric plate 1.

As represented in Figure 1, the phase shifting device varies the phase of the energy in a waveguide system by an amount

$$\Delta\Phi=\Phi_2-\Phi_1$$

As shown in Figures 2–3, the phase shifting device of one embodiment of the present invention comprises a dielectric plate 1 which is mounted on a shaft 4 rotatable about an axis *a*—*a*. The plate 1 is made to project into a hollow waveguide 2 through a slot 3 which runs parallel to the axis A—A of the waveguide 2.

Plate 1 is made preferably of a low-loss dielectric material such as polystyrene. The cross-sectional dimension of the plate 1 is made non-uniform as shown in Figure 3 so that as the plate 1 is rotated about axis *a*—*a* different amounts of material protrude into the waveguide thereby varying the degree of phase shift caused by the dielectric material inside the waveguide.

The dielectric material is preferably placed in the portion of the waveguide having the greatest electric field intensity since in this position it has the greatest affect on the amount of phase shift produced. For the $TE_{1,0}$ mode in a rectangular waveguide, the portion of maximum electric field intensity *e*—*e* runs in the center portion of and parallel to the narrow dimension of the waveguide. Accordingly, slot 3 runs parallel to the axis A—A of, and along the center of the wide side of the rectangular waveguide 2. The axis of rotation *a*—*a* of the plate or wheel 1 is perpendicular to slot 3 so that plate or wheel 1 may readily pass therethrough into the field of greatest electric field intensity of the waveguide 2.

A slot in the walls of a waveguide running perpendicular to the magnetic and electric lines of force in a waveguide will not radiate energy into space. Since a loss of energy is obviously undesirable, having a slot so located is clearly preferred. Slot 3 is in such a position for the $TE_{1,0}$ mode.

The amount of phase displacement caused by inserting

a dielectric material into a waveguide depends on the volume of material so inserted, the dielectric constant of the material, and, as previously discussed, on the electric field intensity into which it is inserted. For the case where a circular disc of homogeneous dielectric material is used whose thickness is varied as shown in Figure 3 of the drawings, the phase displacement is approximately proportional to the mean thickness of the wheel which protrudes into waveguide 1 if the wheel is inserted symmetrically into the waveguide and rotated along an axis which is perpendicular to the axis of the waveguide.

The plate or wheel 1 shown in Figures 2–3 will produce a sinusoidal variation in phase shift as shown in Figure 4. That is to say, if wheel 1 is rotated at a constant rate, the phase shift will continuously vary according to a sine function. One revolution of wheel 1 will produce one period of the sine function.

As shown in Figure 3, the thickness of wheel 1 is gradually increased in a symmetrical manner from one point on the periphery of the wheel to a point on the periphery of the wheel diametrically opposite thereof. The faces of the plate or wheel 1 are in effect formed by two inclined planes P_1, P_2 which intersect at a point F which lies along a line F—F′ which is perpendicular to axis *a—a* of wheel 1. The structure of wheel is thus simple and economical to construct.

If it is desired to increase the amplitude of the sinusoidal phase shift variation, it is only necessary to increase the depth to which the wheel 1 protrudes into waveguide 2. This is accomplished by moving the axis about which plate or wheel 1 rotates closer to waveguide 3 such as along line *b—b*.

The change in phase shift is shown in Figure 4. With the axis of wheel 1 in position *a—a*, if the wheel is rotated by a constant speed motor 5, or by hand, the phase shift variation is shown by the lower curve in Figure 4. The mean phase shift is shown by ordinate *c*. If the axis is moved closer to waveguide 3, the amplitude of the sinusoidal variation is increased along with the mean phase *d* since the average volume of dielectric material protruding into waveguide 2 is thereby increased.

The shape of wheel 1 as shown in Figures 2–3 enables one to conveniently change the amplitude of the sinusoidal phase shift variation.

For some purposes, it is desired to change merely the amplitude of the sinusoidal variation while keeping a constant mean phase. The embodiment of Figures 5–6 enables one to simply achieve such a result.

Referring now to Figure 5, the purpose of this embodiment is to produce a voltage whose phase ϕ_2 relative to the phase ϕ_3 (i. e. $\phi_3-\phi_2$) of another voltage may be varied according to a sinusoidal function whose amplitude may be readily varied but whose mean value remains constant as shown by the curves of Figure 7.

Two phase shifting devices, shown in Figure 6, similar to that just described in connection with Figures 1–3 are utilized. Each device is associated with a different waveguide 2, 2′ and the phase of the energy in each is varied according to a sinusoidal function. Thus wheels 1 and 1′ are caused to protrude through slots 3 and 3′ in the respective waveguides. The two wheels 1, 1′ are kept fixedly related by means of a suitable coupling device 6 which rigidly connects shafts 4 and 4′.

If the wheels 1, 1′ are in a position corresponding to that shown in Figure 6, so that the two wheels are in the same position (relative to the thickness of their cross section), then rotating the wheels together will produce identical instantaneous phase shifts in waveguides 2, and 2′. The phase difference $(\phi_3-\phi_2)$ would therefore be zero if the amplitudes of the sinusoidal phase shifts produced in each waveguide were equal.

If wheel 1′ is rotated relative to wheel 1 to the position shown by the dotted lines in Figure 6, then $\phi_3-\phi_2$, being the difference of two like sinusoidal waveforms displaced in time phase will also be a sinusoidal waveform shown by curve 1 in Figure 7.

If the position of wheel 1′ is fixedly positioned relative to wheel 1 to a position between the solid and dotted positions of Figure 6, then the amplitude variation of the relative phase shift $\phi_3-\phi_2$ will be smaller and displaced in phase as shown by curve 2 in Figure 7. The mean phase difference is still zero. The embodiment of Figures 5–6 thus provides a simple means for progressively varying the ampitude of the sinusoidal phase shift variation where the mean phase shift remains zero.

Although the embodiments of Figures 1–6 disclose a circular dielectric wheel which rotates about an axis at the center thereof whose thickness gradually varies to produce a change in phase shift, other types of wheels may be used, one example of which is shown in Figure 8, if other than a sinusoidal phase shift variation is desired. The wheel 1″ there shown comprises a circular disc of constant thickness whose axis of rotation is along a point 7 which is off center. The distance the wheel protrudes into the waveguide is thus varied as the wheel is rotated. This design has the disadvantage that one cannot vary the amplitude over as wide a limit as in the design where the thickness of the circular wheel is varied as in the preferred embodiment of Figures 1–6.

The largest possible phase shift variation for a single revolution of the dielectric wheel is obtained where the thickness of the wheel of the embodiment of Figure 8 is varied like wheel 1 in Figure 6. In effect, this is a combination of the features of the wheel in Figures 1–6 with that of Figure 8.

Instead of changing the volume of dielectric material which protrudes into hollow waveguide 2, the dielectric constant of the material protruding into the waveguide may be varied. Figure 9 shows a circular dielectric plate 1″ having a constant thickness whose axis of rotation is in the center thereof. The plate consists of sections 6′—7 which are made of dielectric materials having different dielectric constants. As plate 1″ is rotated, the degree of phase shift varies because the ratio of the volume of dielectric material of section 6′ to that of section 7 which protrudes into waveguide 2 varies with its angular position.

It is to be noted that the phase shift of energy in waveguide 2 could also be varied by mounting the axis of the dielectric wheel parallel to the axis A—A of the waveguide. A slot would then be cut in the waveguide running perpendicular to the waveguide axis A—A. This would be undesirable from many viewpoints. First of all such a slot would radiate energy and thereby cause undesirable losses. Secondly, if the wheel would protrude substantially into the waveguide the problem of mismatch is greatly increased over that caused by the preferred embodiment of Figures 1–6.

Although a rectangular waveguide operated in the $TE_{1,0}$ mode has been disclosed, the present invention has application with other types of waveguides and modes.

Many other modifications may be made of the specific embodiments first disclosed without deviating from the scope of the present invention.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. Apparatus for producing a sinusoidal variation in the phase shift of energy in a hollow waveguide system comprising a circular plate made of a dielectric material rotatably mounted about a given axis, said axis being in the center of said plate, the thickness of said plate gradually increasing in value from one edge to the other diametrically opposite edge thereof, said plate protruding into a hollow waveguide through a narrow slot in the walls thereof, said slot being parallel to the axis of the waveguide, said given axis being perpendicular to said waveguide axis, means for rotating said plate at a constant

angular rate whereby the phase of said energy varies continuously according to a sine function.

2. Apparatus for producing a sinusoidal variation in the phase shift of energy in a hollow waveguide system comprising a circular plate made of a low-loss dielectric material rotatably mounted about a given axis, said axis being in the center of said plate, the thickness of said plate linearly increasing in value from one edge to the other diametrically opposite edge thereof, said plate protruding into a hollow waveguide through a narrow slot in the walls thereof, said slot being parallel to the axis of the waveguide, said given axis being perpendicular to said waveguide axis.

3. Apparatus for producing a sinusoidal variation in the phase shift of energy in a hollow waveguide system comprising a circular plate made of a dielectric material rotatably mounted about a given axis, said axis being in the center of said plate, said plate protruding into a hollow waveguide through a narrow slot in the walls thereof extending lengthwise of said waveguide, the thickness of

the portions of said plate which protrude into said slot as said plate is rotated gradually increasing in value from one side of said plate to the diametrically opposite side thereof.

References Cited in the file of this patent

UNITED STATES PATENTS

2,423,150	Lindenblad	July 1, 1947
2,426,992	Folland et al.	Sept. 9, 1947
2,433,368	Johnson et al.	Dec. 30, 1947
2,495,170	Kinn	Jan. 17, 1950
2,505,557	Lyman	Apr. 25, 1950

FOREIGN PATENTS

802,756	France	June 13, 1936
591,369	Great Britain	Aug. 15, 1947

OTHER REFERENCES

Kallmann, H. E.: "Standing Wave Meter," Electronics, January 1947, page 96.