

Aug. 20, 1946.

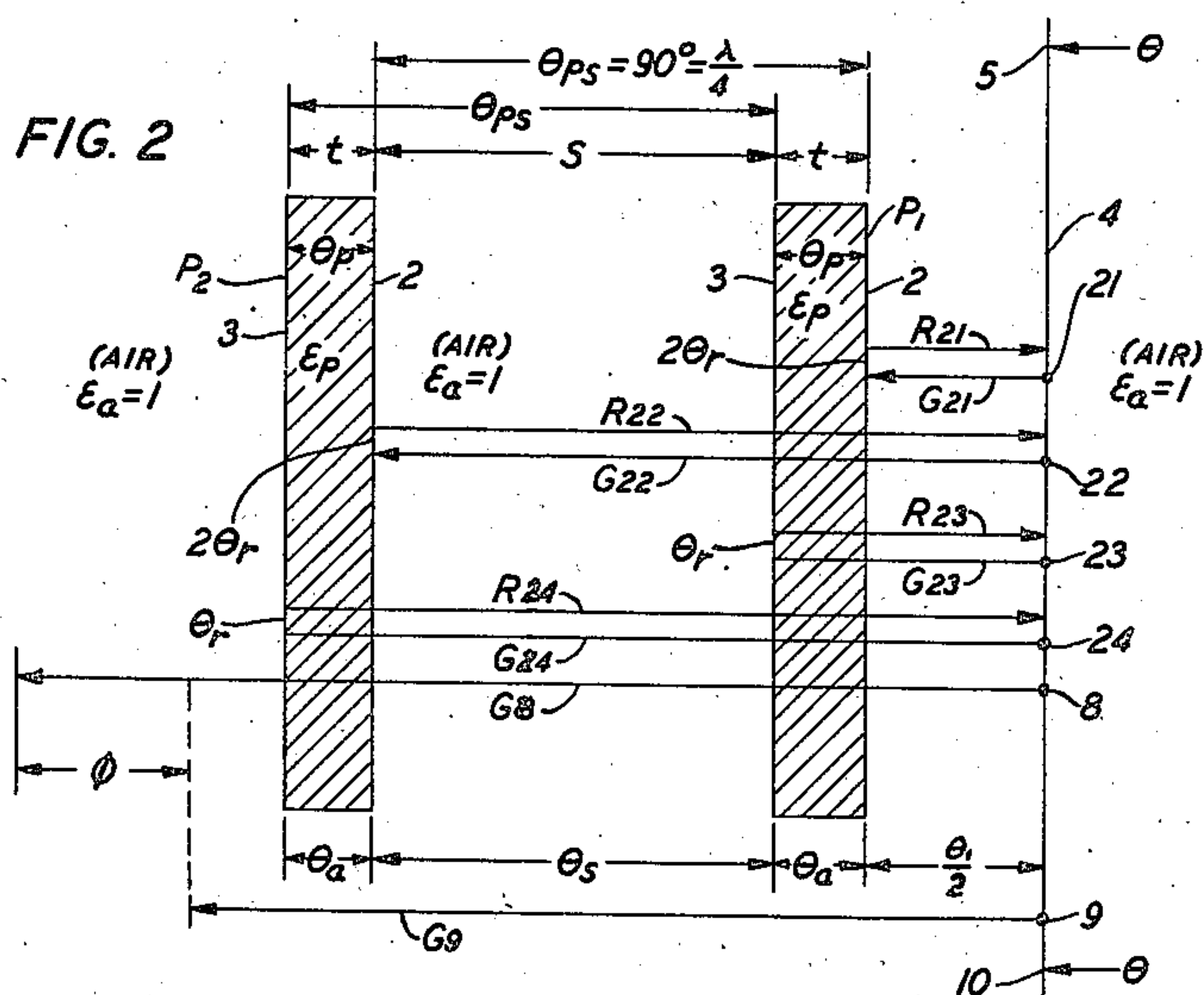
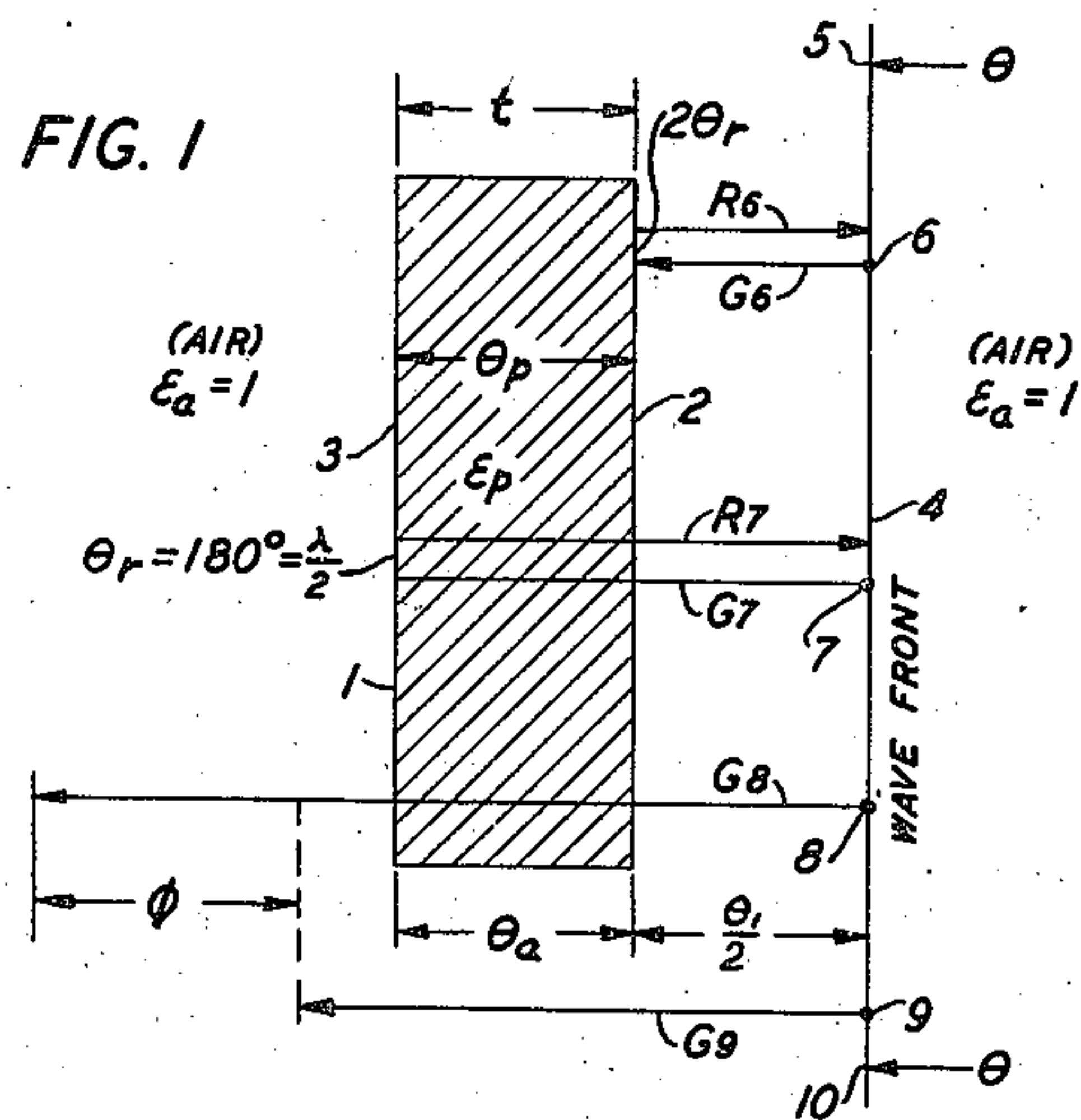
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2,405,992

DIRECTIVE ANTENNA SYSTEM

Filed Jan. 19, 1944

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 3

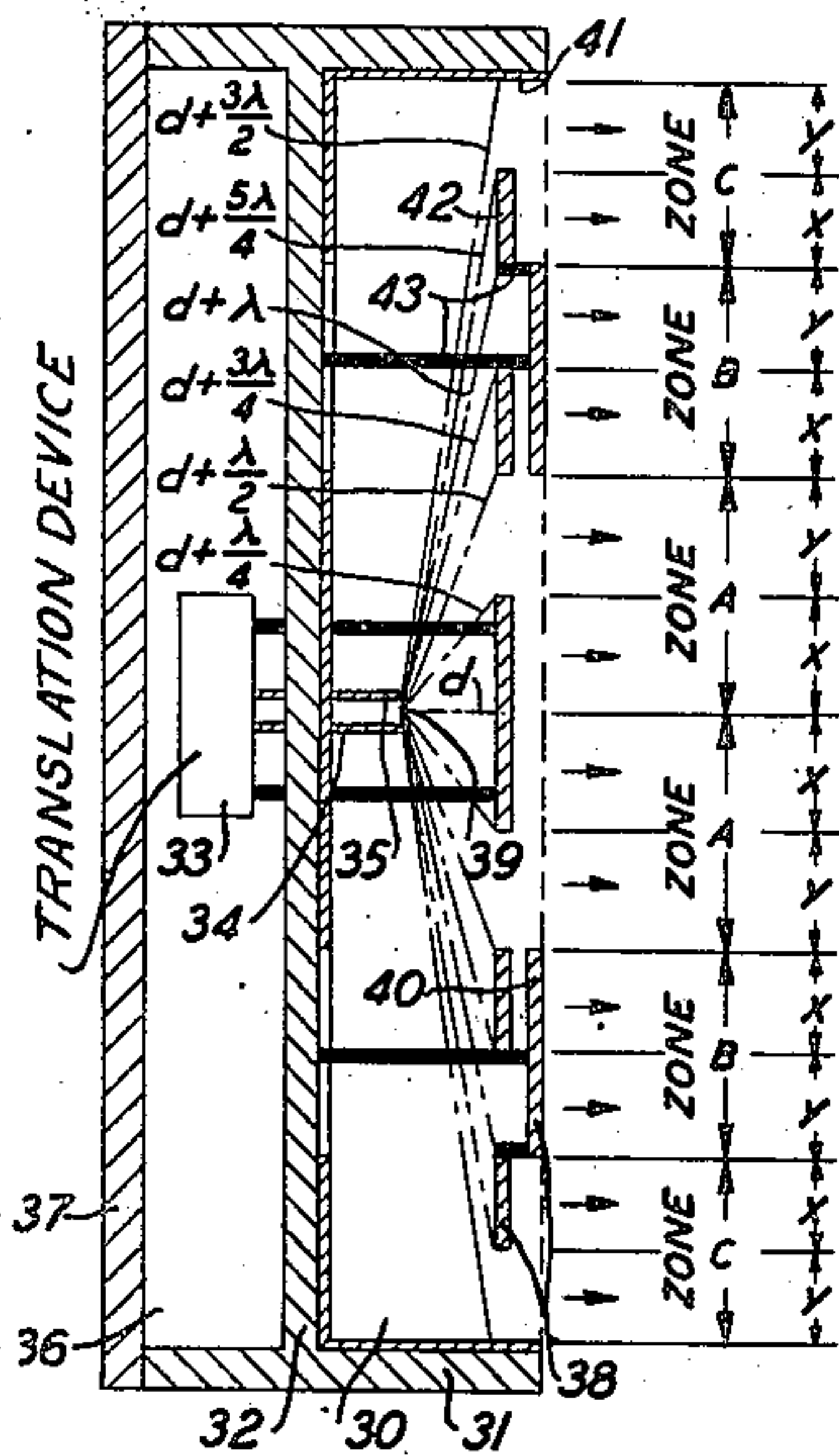


FIG. 5

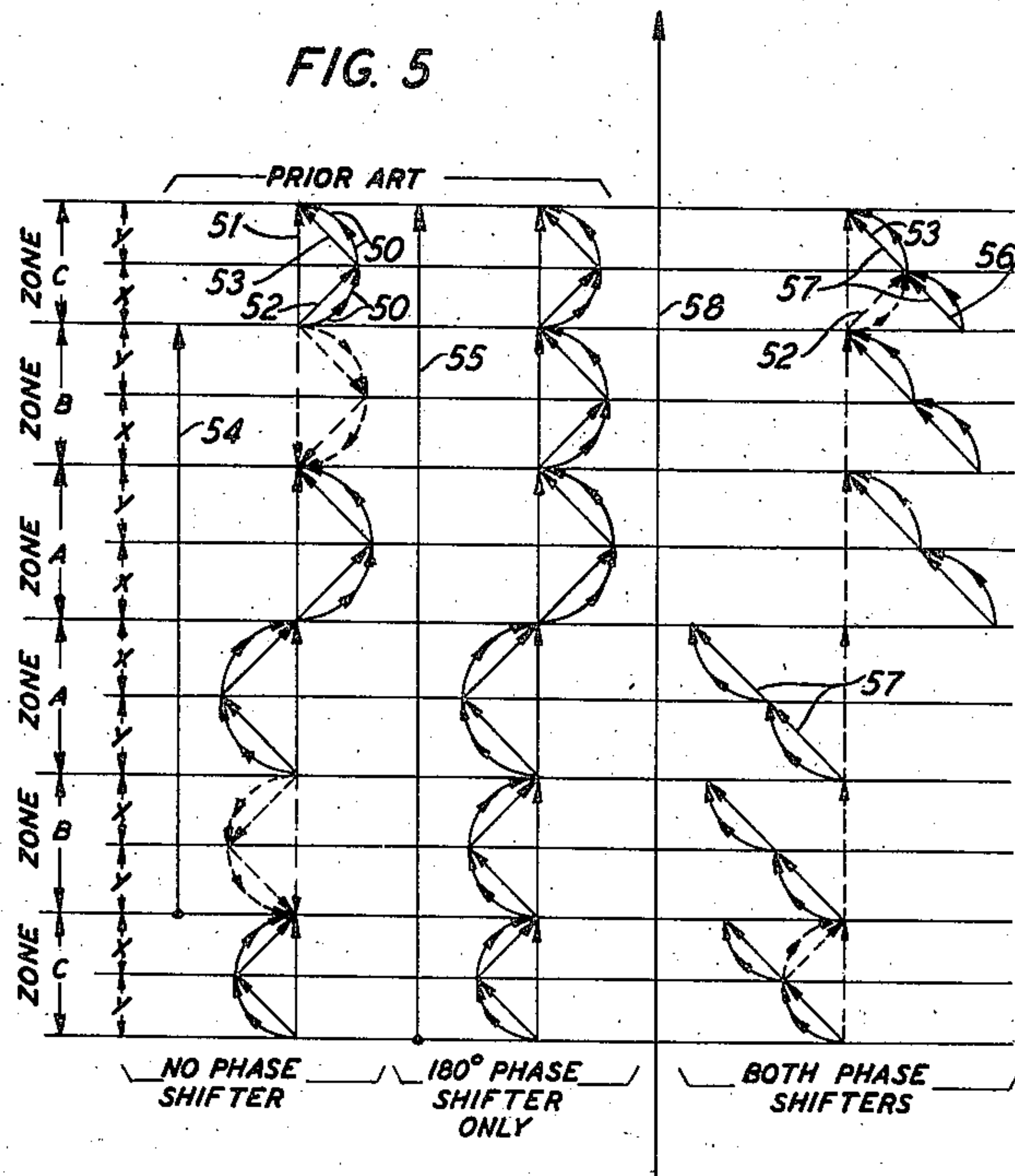
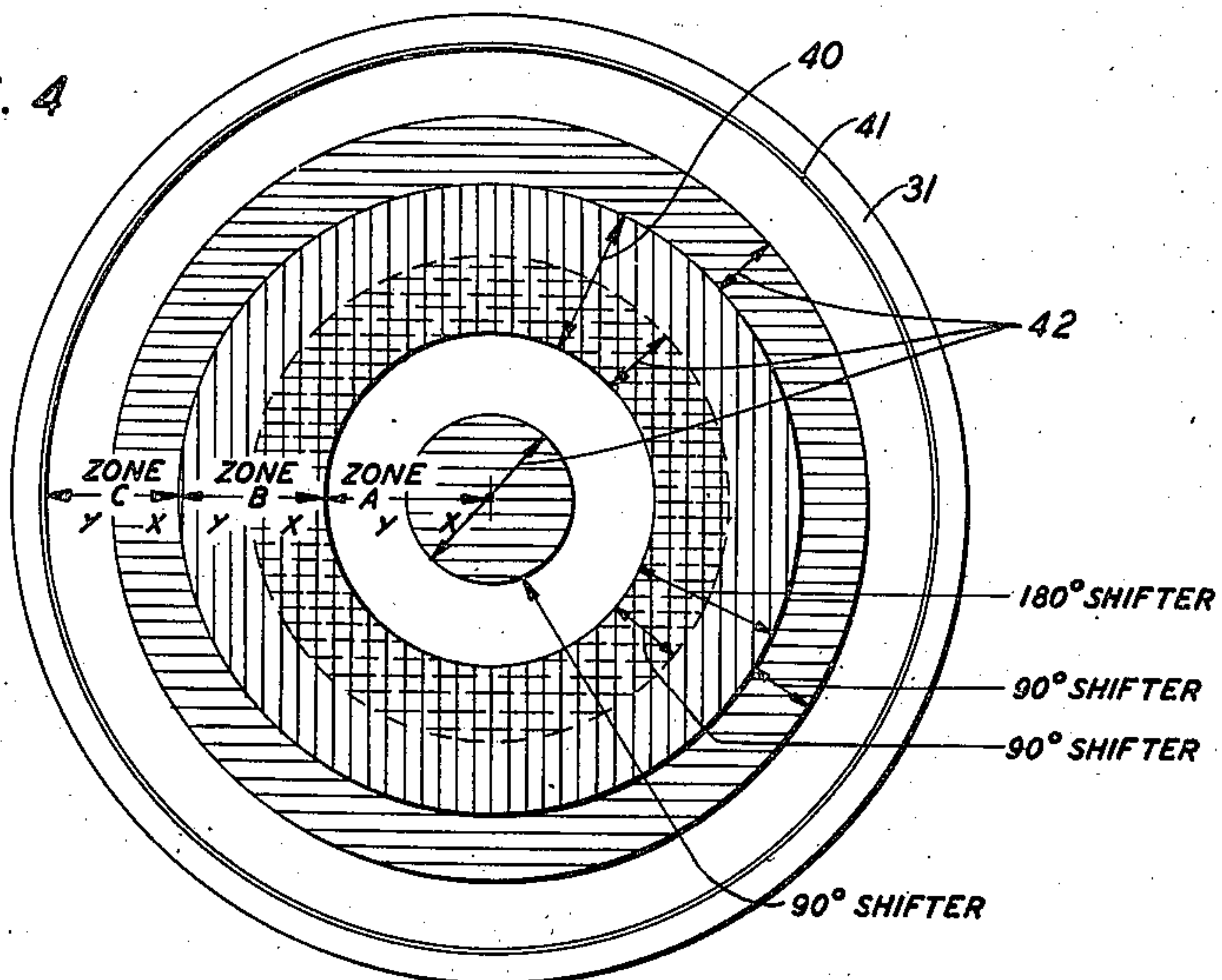


FIG. 4



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DIRECTIVE ANTENNA SYSTEM

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Application January 19, 1944, Serial No. 518,791

15 Claims. (Cl. 250—11)

1

This invention relates to phase shifters and particularly to phase shifters of the dielectric zone plate type used in directive single zone and multiple zone antenna systems.

As disclosed in my copending application, Serial No. 400,319 filed June 28, 1941, a low attenuation dielectric plate may be utilized for changing, without reflection loss, the phase of a wave component passing through the plate nearly 180 degrees relative to that of a component propagated along an adjacent path in the ether having a length equal to the physical thickness of the plate. While, as explained in the above-mentioned application, the reflectionless phase reversing plate is highly useful in microwave transmission and antenna systems, it now appears advantageous also to employ in certain radio systems dielectric means for securing without reflection loss, any desired relative phase shift. In accordance with the present invention, a pair of low attenuation dielectric plates or a single low attenuation dielectric plate is used to obtain, without reflection loss, any desired phase shift.

In addition, as disclosed in my aforementioned copending application and in Patents 2,043,347 granted on June 9, 1936, to A. G. Clavier et al., and 2,169,553 granted on August 15, 1939 to applicant, highly directive antenna action may be secured by utilizing with a substantially non-directive primary antenna element a plane grating having one or more zones. The grating functions to convert the divergent beams into parallel beams. In accordance with the present invention the gains of the single zone and multiple zone antenna systems referred to above are greatly increased.

It is one object of this invention to obtain one or more dielectric plates for changing the relative phase of a radio wave any predetermined amount without reflection loss.

It is another object of this invention to obtain a lossless quadrature phase shifter of the dielectric plate type.

It is still another object of this invention to increase the gain of a directive antenna comprising a grating.

It is a further object of this invention to increase, in a grating-type antenna system, the total amplitude of the waves in each zone.

In accordance with one embodiment of the invention the gain of the single zone or multiple zone directive antenna system disclosed in the aforementioned patents and having one set of alternate active zones, is increased by utilizing

2

in one-half of each active zone a quadrature phase shifter constructed in accordance with the invention and comprising a plane single half zone dielectric plate or a pair of parallel half zone dielectric plates. In accordance with another embodiment of the invention, the gain of the single zone or multiple zone directive antenna system disclosed in my aforesaid copending application and having all zones active, is increased by placing a quadrature phase shifter constructed in accordance with the invention in one-half of each zone of the grating. The quadrature phase shifter functions to change the phase vector for the associated half zone 90 degrees, and therefore to align the two vectors for the inner and outer halves of the annular zone, whereby the over-all intensity of the energy passing through the zone is increased.

If, in the system just described, a single plate is employed as the quadrature phase shifter, the dielectric constant and thickness of the plate are, in accordance with the invention, such that the phase shift in the plate is 180 degrees, and the phase shift along an ether path corresponding in length to the path in the plate is equal to 90 degrees, that is, 180 degrees minus the predetermined desired relative phase shift of 90 degrees. By reason of the thickness of the plate as measured in wavelengths in the plate, the waves impinging upon the plate and reflected at the front surface of the plate and the waves entering the plate and reflected by the rear surface are oppositely phased with the result that there is no reflection loss. If desired, several parallel thin plates may be used for securing, without reflection, a 90-degree phase shift in place of a single thick plate. Thus two plates having equal dielectric constants and equal thicknesses may be used. The phase shift in each plate minus the phase shift along a correspondent ether path is equal to one-half of the desired relative phase shift of 90 degrees. The spacing between the correspondent front faces, or the correspondent rear faces, is such that the electrical path connecting the correspondent faces and comprising the dielectric path in one plate and the ether path between the plates is 90 degrees, whereby the waves reflected by the two front faces cancel and the waves reflected by the two rear faces of the plate cancel. Stated differently, the vector sum of the reflections from the four faces equals zero.

In addition, in accordance with the invention, the single plate phase shifter, and each plate in the double plate phase shifter, may have a di-

3

electric constant and a physical thickness for securing any phase shift other than 90 degrees. The thickness of the single plate as measured in wavelengths in the plate is always 180 degrees or an odd integral multiple thereof, and the spacing between correspondent faces of the plates in the double plate shifter always corresponds to 90 degrees, or an odd integral multiple thereof, so that all reflected waves are canceled.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawings on which like reference characters denote elements of similar function, and on which:

Fig. 1 is a side view of a single plate phase shifter of the invention;

Fig. 2 is a side view of a double plate phase shifter constructed in accordance with the invention;

Figs. 3 and 4 are respectively a side cross-sectional view and a front view of one embodiment of the invention comprising a multiple zone directive antenna equipped with half zone dielectric plates; and

Fig. 5 is a vector diagram used in explaining the operation of the system of Figs. 3 and 4.

Referring to the single plate shifter shown in Fig. 1, reference numeral 1 denotes a plate composed of dielectric material, such as titanium dioxide set in rubber, resin, Micarta, or a mixture of resin and beeswax. The plate has a physical thickness t and a dielectric constant E_p . The air medium in which the plate is immersed has a dielectric constant E_a equal to unity. Numerals 2 and 3 denote, respectively, the front and rear faces of plate 1 and numeral 4 designates the advancing wave front of an incoming wave. The typical or representative components 5, 6, 7, 8, 9 and 10 in the wave front have, for the wave front position illustrated, the same phase θ . The reference character G_6 denotes the "go" or forward path traversed by component 6 in reaching the front face 2 and the character R_6 denotes the "return" path followed by component 6 after reflection by the front face 2. Similarly, the reference characters G_7 and R_7 denote, respectively, the go and return paths for component 7 which enters the plate and is reflected by the rear face 3. Reference characters G_8 and G_9 denote, respectively, the go path of component 8 which passes through the plate and component 9 which avoids the plate.

In operation, considering the reflected components 6 and 7, both components undergo a phase shift of

$$\frac{\theta_1}{2}$$

in reaching the plate. Component 6 does not undergo a phase reversal upon reflection at the front face 2 since the wave at this face is passing from a rare to a dense medium. On the other hand component 7 undergoes upon reflection at the rear face 3 a phase reversal since the wave is passing from a dense to a rare medium. On the drawings θ_r , equal to 180 degrees, represents the phase reversal. In addition, component 7 undergoes a shift of $2\theta_p$ in traversing the plate twice. The thickness t and the constant E_p are selected so that θ_p equals 180 degrees, E_p being unequal to unity. Stated differently, the thickness t equals

$$\frac{\lambda_p}{2}$$

where λ_p is the wavelength as measured in the

4

dielectric forming the plate, and therefore does not equal

$$\frac{\lambda_a}{2}$$

where λ_a is the wavelength as measured in the air. Hence we have for component 6 a phase change θ_6

$$\theta_6 = \frac{\theta_1}{2} + 0 + \frac{\theta_1}{2} = \theta_1 \quad (1)$$

and for component 7

$$\theta_7 = \frac{\theta_1}{2} + \theta_p + \theta_r + \theta_p + \frac{\theta_1}{2} = \theta_1 + 2\theta_p + \theta_r \quad (2)$$

$$\theta_7 - \theta_6 = (360 + 180) \text{ degrees} \quad (3)$$

Since components 6 and 7 arriving over paths R_6 and R_7 at the front 4 are oppositely phased they cancel and reflection is eliminated.

Considering components G_8 and G_9 , component G_8 undergoes a phase shift of

$$\frac{\theta_1}{2}$$

in reaching the plate and, in the plate, a phase shift of θ_p . The component 9 undergoes a phase shift

$$\frac{\theta_1}{2}$$

and a phase shift θ_a in moving along an ether path having a length equal to the plate thickness t , as measured in wavelengths in the air. Hence the desired or final relative phase shift for components 8 and 9 is

$$\Phi = \theta_p - \theta_a = 180 \text{ degrees} - \theta_a \quad (4)$$

It follows that any desired relative phase shift may be secured, without reflection loss, by selecting a plate having a dielectric constant and a physical thickness, as measured in wavelengths in the air, such that e equals

$$\frac{\lambda_p}{2}$$

whereby θ_p equals 180 degrees and θ_a equals 180 degrees minus the desired phase shift Φ . To illustrate, if E_p has a value such that

$$t = \frac{\lambda_p}{2} = \frac{\lambda_a}{4} \quad (5)$$

then

$$\Phi = \theta_p - \theta_a = (180 - 90) \text{ degrees} = 90 \text{ degrees}$$

and we have a lossless quadrature phase shifter. If E_p is such that

$$t = \frac{\lambda_p}{2} = \frac{\lambda_a}{8} \quad (6)$$

$$\Phi = 135 \text{ degrees}$$

The manner of determining E_p for any particular phase shift will now be determined. Thus

$$\theta_p = \frac{2\pi t}{\lambda_p} \quad (7)$$

$$\theta_a = \frac{2\pi t}{\lambda_a} \quad (8)$$

$$\Phi = \theta_p - \theta_a = \frac{2\pi t}{\lambda_p} - \frac{2\pi t}{\lambda_a} \quad (9)$$

But

$$\lambda_p = \frac{\lambda_a}{\sqrt{E_p}} \quad (10)$$

so that

$$\Phi = \frac{2\pi t}{\lambda_a} (\sqrt{E_p} - 1) \quad (11)$$

5

For the condition of no reflection

$$t = \frac{\lambda_p}{2}(2m+1) = \frac{\lambda_a}{2\sqrt{E_p}}(2m+1) \quad (12)$$

where m is any integer including zero.

Substituting (12) in (11) we have

$$\Phi = \pi \left(1 - \frac{1}{\sqrt{E_p}}\right)(2m+1) \quad (13)$$

Letting m equal zero and

$$\Phi = \frac{\pi}{2} = 90 \text{ degrees}$$

$$\sqrt{E_p} = 2 \quad (14)$$

and

$$E_p = 4 \quad (15)$$

Substituting this value of E_p and $m=0$ (12), we have

$$t = \frac{\lambda_p}{2} = \frac{\lambda_a}{4} \quad (16)$$

Accordingly, a plate having a dielectric constant of 4 and a thickness of a quarter air wavelength is a lossless quadrature phase shifter. In one system actually tested and utilizing an operating air wavelength of 11.2 centimeters, a plate composed of resin and beeswax and having a thickness of 2.3 centimeters, functioned satisfactorily. To secure a phase shift of 135 degrees, that is,

$$\frac{3\pi}{4}$$

without reflection loss the constant E_p must equal 16 by Equation 13 where $m=0$, and

$$\frac{\lambda_p}{2}$$

must equal

$$\frac{\lambda_a}{8}$$

In general, for any desired relative phase shift, the relation between the thickness t and the dielectric constant E_p is given by the Equation 13.

Referring to the double plate shifter shown in Fig. 2, reference letters P_1 and P_2 denote a pair of parallel dielectric plates spaced a distance s and having the same thickness t and the same dielectric constant E_p . Each plate has a front face 2 and a rear face 3. The spacing s between the plates is such that the length of the path θ_{ps} between the corresponding front faces 2, or between the rear faces 3, is 90 degrees or an odd integral multiple thereof. Expressed mathematically

$$\frac{2\pi t}{\lambda_p} + \frac{2\pi s}{\lambda_a} = 90 \text{ degrees} = \frac{\pi}{2}(2m+1) \quad (17)$$

where m is any integer including zero, or

$$\theta_p + \theta_s = 90 \text{ degrees} = \frac{\pi}{2}(2m+1) \quad (18)$$

where θ_s is the phase shift corresponding to the ether path between the plates.

Numerals 5, 8, 9, 10, 21, 22, 23 and 24 denote components in the wave front 4. As indicated by the go and return paths G_{21} and R_{21} , component 21 is reflected by the front face 2 of plate P_1 . Similarly, as shown by the paths G_{22} and R_{22} , component 22 is reflected by the front face 2 of plate P_2 . These components are not changed in phase upon reflection. Component 23 is, as indicated by the paths G_{23} and R_{23} , reflected with a phase reversal by the rear face 3 of plate P_1 and com-

6

ponent 24 is similarly reflected by the rear face 3 of plate P_2 , as shown by the paths G_{24} and R_{24} .

Considering components 21 and 22, we have for component 21 a phase shift

$$\theta_{21} = \frac{\theta_1}{2} + 0 + \frac{\theta_1}{2} = \theta_1 \quad (19)$$

and for component 22

$$\theta_{22} = \frac{\theta_1}{2} + \theta_p + \theta_s + 0 + \theta_s + \theta_p + \frac{\theta_1}{2} \quad (20)$$

$$= \theta_1 + 2\theta_p + 2\theta_s = \theta_1 + 2(\theta_p + \theta_s) \quad (21)$$

$$= \theta_1 + 180 \text{ degrees} \quad (22)$$

$$\theta_{22} - \theta_{21} = 180 \text{ degrees} \quad (23)$$

and the reflected components 21 and 22 cancel each other.

Considering components 23 and 24, we have for component 23

$$\theta_{23} = \frac{\theta_1}{2} + \theta_p + \theta_r + \theta_p + \frac{\theta_1}{2} \quad (24)$$

$$= \theta_1 + 2\theta_p + \theta_r \quad (25)$$

where, as in Fig. 1, θ_r equals 180 degrees.

For component 24 we have

$$\theta_{24} = \frac{\theta_1}{2} + \theta_p + \theta_s + \theta_p + \theta_r + \theta_p + \theta_s + \theta_p + \frac{\theta_1}{2} \quad (25A)$$

$$= \theta_1 + 4\theta_p + 2\theta_s + \theta_r \quad (26)$$

and from (25) and (26)

$$\theta_{24} - \theta_{23} = 2\theta_p + 2\theta_s = 2(\theta_p + \theta_s) = 2\theta_{ps} = 180 \text{ degrees} \quad (27)$$

Hence reflected components 23 and 24 cancel each other. Considered differently, the vector sum of components 21, 22, 23 and 24 equals zero. In this connection it should be pointed out that the plates are preferably composed of dielectric materials in which the energy losses are negligible, in order to secure maximum cancellation of the reflected waves. Accordingly, by spacing the plates a critical distance dependent upon the thickness t of each plate, as measured in wavelengths in the dielectric, reflection is eliminated.

Referring to component 8 which passes through both plates and component 9 which avoids both plates, the relative phase shift Φ is

$$\Phi = [\theta_p + \theta_s + \theta_p] - [\theta_a + \theta_s + \theta_a] \quad (28)$$

$$\Phi = 2\theta_p - 2\theta_a = 2(\theta_p - \theta_a) \quad (29)$$

$$\frac{\Phi}{2} = \theta_p - \theta_a \quad (30)$$

From Equation 29 if

$$\theta_p = 45 \text{ degrees} + \theta_a \quad (31)$$

$$\Phi = 2(45 \text{ degrees} + \theta_a) - 2\theta_a \quad (32)$$

$$\Phi = 90 \text{ degrees} \quad (33)$$

Preferably, but not necessarily, the plates have equal dielectric constants and equal thicknesses. They may have any selected dielectric constant, and a thickness dependent thereon, for securing a desired phase shift Φ , or they may have any selected thickness depending upon the dielectric constant. The relation between the desired phase shift Φ , the thickness t , the dielectric constant E_p and the spacing s is given in the following equations. Thus, for each plate

$$\frac{\Phi}{2} = \frac{2\pi t}{\lambda_p} - \frac{2\pi t}{\lambda_a} \quad (34)$$

Substituting from Equation 10

$$\frac{\Phi}{2} = \frac{2\pi t}{\lambda_a} (\sqrt{E_p} - 1) \quad (35)$$

$$t = \frac{\Phi \lambda_a}{4\pi (\sqrt{E_p} - 1)} \quad (36)$$

By Equation 17

$$(2m+1) \frac{\pi}{2} = \frac{2\pi s}{\lambda_a} + \frac{2\pi t}{\lambda_p} = \frac{2\pi s}{\lambda_a} + \frac{2\pi t \sqrt{E_p}}{\lambda_a} \quad (37)$$

$$s = (2m+1) \frac{\lambda_a}{4} - t \sqrt{E_p} \quad (38)$$

In Equation 38, m should be an integer sufficiently large to make s positive. As an example, where $m=0$, if

$$\Phi = \frac{\pi}{4} = 45 \text{ degrees}$$

and

$$\sqrt{E_p} = 4, t = \frac{\lambda_a}{48} \text{ and } s = \frac{\lambda_a}{6}$$

If desired, three or more dielectric plates having different thicknesses and different dielectric constants may be used to secure a non-reflective phase shifter. The spacings between plates should be such that the vector sum, as measured at the first or initial surface, of the reflections from all surfaces equals or approaches zero. The phase shift obtained equals the total thickness of the plates as measured in wavelengths in the plates minus the total thickness as measured in wavelengths in the air.

Referring to Figs. 3 and 4, numeral 30 denotes a drum-type reflector similar to that disclosed in my aforementioned patent and copending application, the primary difference being that the drum opening is circular instead of oval. The drum 30 comprises a cylindrical wall 31 and an end plane reflector 32. Numeral 33 denotes a translation device, such as a transmitter or a receiver, which is connected to a wave guide 34 having an end aperture 35 constituting a so-called "point" source or collector. The device 33 is mounted on the inactive side of reflector plate 32 and inside the compartment 36 formed by the extension of the drum 30 and the cover member 37. Reference numeral 38 denotes a grating positioned in the drum opening and having a focus 39, an axis and a focal length d measured along the axis. The grating 38 comprises the concentric annular zones A, B and C, each having an inner half zone x and an outer half zone y . The primary antenna or aperture 35 is positioned at the focus 39 of the grating. In accordance with the disclosure in my copending application, zone B is equipped with a full zone dielectric plate 40 which functions to reverse the phase of the vector for the zone without reflection loss. As explained in my patent mentioned above, the inside surface of wall 31 and the areas of reflector 32 facing zones A and C are lined with copper 41. In accordance with the present invention, the inner half of each zone is equipped with a half zone dielectric plate 42, such as illustrated by Fig. 1, the half zone plate being designed to secure a 90-degree phase shift without reflection loss. The distances from the focus 39 to the inner or near edge and to the outer or far edge of the plate 42, in each zone, differ a quarter wavelength as measured in the air. Numerals 43 denote struts for rigidly attaching device 31 and plates 40 and 42 to the reflector plate 32.

In operation, assuming the system of Figs. 3 and 4 is employed for receiving energy, the incoming wave having a wave front parallel to the drum opening and grating 38 passes through zones A, B and C. The wavelets entering air zones A and C are focused upon and arrive in phase at the aperture 35; and the wavelets in zone B are reversed in phase and arrive at aperture in phase with the wavelets from zones A and C. As will now be explained the quadrature phase shifter 42 functions to increase the total intensity of the energy passing through each zone.

Referring to Fig. 5, and assuming for the moment that the half zone plates 42 are omitted, the phase vectors 50 of the wavelets in any zone as, for example, zone C and passing along the extreme opposite boundaries of the zone are oppositely directed, and the components passing through the intermediate zone portions have slightly different phase vectors so that the wavelet vectors form a semicircle the diameter 51 of which is the vector resultant for the full zone. The zone vector 51 may be considered as comprising two quadrature half zone vectors 52 and 53 representing, respectively, the inner and outer half zones x and y . Assuming further that zone B is equipped with a metallic zone plate, as disclosed in my aforementioned patent, the oppositely phased wavelets of zone B are eliminated and the vectors 51 of zones A and C combine to give an over-all vector resultant 54. If zone B is equipped with a dielectric phase shifter, as in Figs. 3 and 4 and in the system of my copending application, the vectors of zones A, B and C combine in phase to produce the much larger vector resultant 55. With a quadrature phase shifter in the inner half zone x , the vector 52 for this half zone is rotated 90 degrees to the position denoted by numeral 56, and the two half zone vectors are rendered colinear. As a result, the length of the zone vector is increased and the gain of the zone enhanced, the sum denoted by numeral 57 of vectors 53 and 56 being greater than the length of vector 51. All the parallel zone vectors 57 combine to produce the resultant vector 58 which is much longer than the vectors 54 and 55 for the prior art systems. Hence, in accordance with the invention, the gain of each active zone is increased; and the gain of the entire grating or system is relatively great as compared to the prior art arrangements. If desired, a double plate quadrature phase shifter such as that shown in Fig. 2 may be used in place of the single plate shifter 42.

In the system of Figs. 3 and 4, and in the diagram of Fig. 5, it has been assumed that the primary antenna 35 is a point source. If a dipole is used at the focus of the grating, the plates 40 and 42 are preferably orbicular instead of circular, in accordance with the disclosure in my copending application, the minor and major diameters or dimensions of each plate being different by an amount equal to the dipole length.

Although the invention has been described in connection with certain embodiments, it is to be understood that it is not to be limited to the described embodiments inasmuch as other apparatus may be successfully utilized without exceeding the scope of the invention.

What is claimed is:

1. A phase shifter for passing a wave of given wavelength and for changing without reflection loss the phase of said wave, said shifter being composed of dielectric material and having at least two faces extending perpendicular to the

9

direction of said wave, the path aligned with said direction and connecting said faces being equivalent to a multiple, including the integer one, of 90 degrees, and the difference between the dimension along said path of the material as measured in wavelengths in the material and the dimension as measured in wavelengths in the air being equivalent to a phase shift smaller or greater than 180 degrees.

2. A phase shifter for securing a desired phase shift without reflection loss comprising a plate composed of dielectric material, said plate having a thickness of a half wavelength as measured in the plate and a thickness equal to a half wavelength minus said desired phase shift, as measured in the air.

3. A 90-degree phase shifter comprising a dielectric plate having a dielectric constant equal to four and a thickness of a half wavelength as measured in the plate and a quarter wavelength as measured in the air.

4. A phase shifter for securing a desired phase shift without reflection loss comprising a pair of parallel dielectric plates, the spacing between plates being equivalent to 90 electrical degrees minus the electrical degrees corresponding to the thickness of one plate as measured in wavelengths in the plate.

5. A phase shifter for securing a desired phase shift without reflection comprising a plurality of plates each composed of dielectric material and having two faces extending parallel to an incoming wave front, the difference in electrical length between the paths connecting said wave front and any one of said faces and connecting said wave front and another of said faces being 90 degrees, and the difference between the total thickness of said plates as measured in wavelengths in the air and as measured in the materials composing said plates being equal to the desired phase shift.

6. A non-reflective phase shifter for securing a desired phase shift comprising a plurality of dielectric plates spaced along the direction of an incoming wave and each having a pair of faces angularly related to said direction, the electrical lengths of the paths along said direction between the front face of the plate first traversed by the incoming wave and each of the other faces of said plates being related to the thickness and dielectric constants of said plates, whereby the vector sum as at said front face of all waves reflected by all of said faces equals zero substantially.

7. A phase shifter for securing a desired phase shift with reflection cancellation comprising a pair of parallel dielectric plates having the same thickness and the same dielectric constant, the difference between the thickness of each plate as measured in wavelengths in the plate and the

10

thickness of each plate as measured in wavelengths in the air being equal to one-half the desired phase shift.

8. A phase shifter in accordance with the preceding claim, each of the two paths connecting corresponding faces of the plates having a length equivalent to 90 degrees.

9. In combination, a multiple zone grating comprising a plurality of concentric full-zone diffraction plates positioned in a first set of alternate zones of said grating and each having a focus, means at said focus for energizing one set of alternate zones of said grating with similarly phased waves and the other or second set of alternate zones with oppositely phased waves, and quadrature phase shifting means in one-half of each zone of one set of alternate zones.

10. A combination in accordance with claim 9, said means comprising a circular half zone dielectric plate.

11. A combination in accordance with claim 9, said means comprising a half zone dielectric plate positioned in the inner half of the zone.

12. A combination in accordance with claim 9, and quadrature phase shifting means in one half of each zone of the second set of alternate zones.

13. In an antenna system, a drum reflector having an opening, a multiple zone grating positioned in said opening and comprising a plurality of concentric full-zone diffraction plates having a common focus, a primary antenna at said focus, and phase shifting means positioned in each zone.

14. In combination, an antenna element at a given point for transmitting or receiving a wave having a given wavelength and a circular wave front, diffraction means for changing an incoming plane wave front into a circular wave front and for changing an outgoing circular wave front into a plane wave front, said diffraction means comprising at least one full-zone plate and at least one half-zone dielectric plate each having a face parallel to said plane wave fronts, the difference in the distances from said point to the edges of said full-zone plate face farthest from and nearest to said point being equal to one-half of said wavelength, the difference in the distances from said point to the edges of the half-zone plate face farthest from and nearest to said point being equal to a quarter of said wavelength, one of the aforementioned edges of said full-zone plate face and one of the aforementioned edges of said half-zone plate face being at substantially the same distance from said point.

15. A combination in accordance with claim 14, said half-zone plate having a thickness of a half-wavelength as measured in the plate and a quarter wavelength as measured in the air.

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