

Dec. 10, 1946.

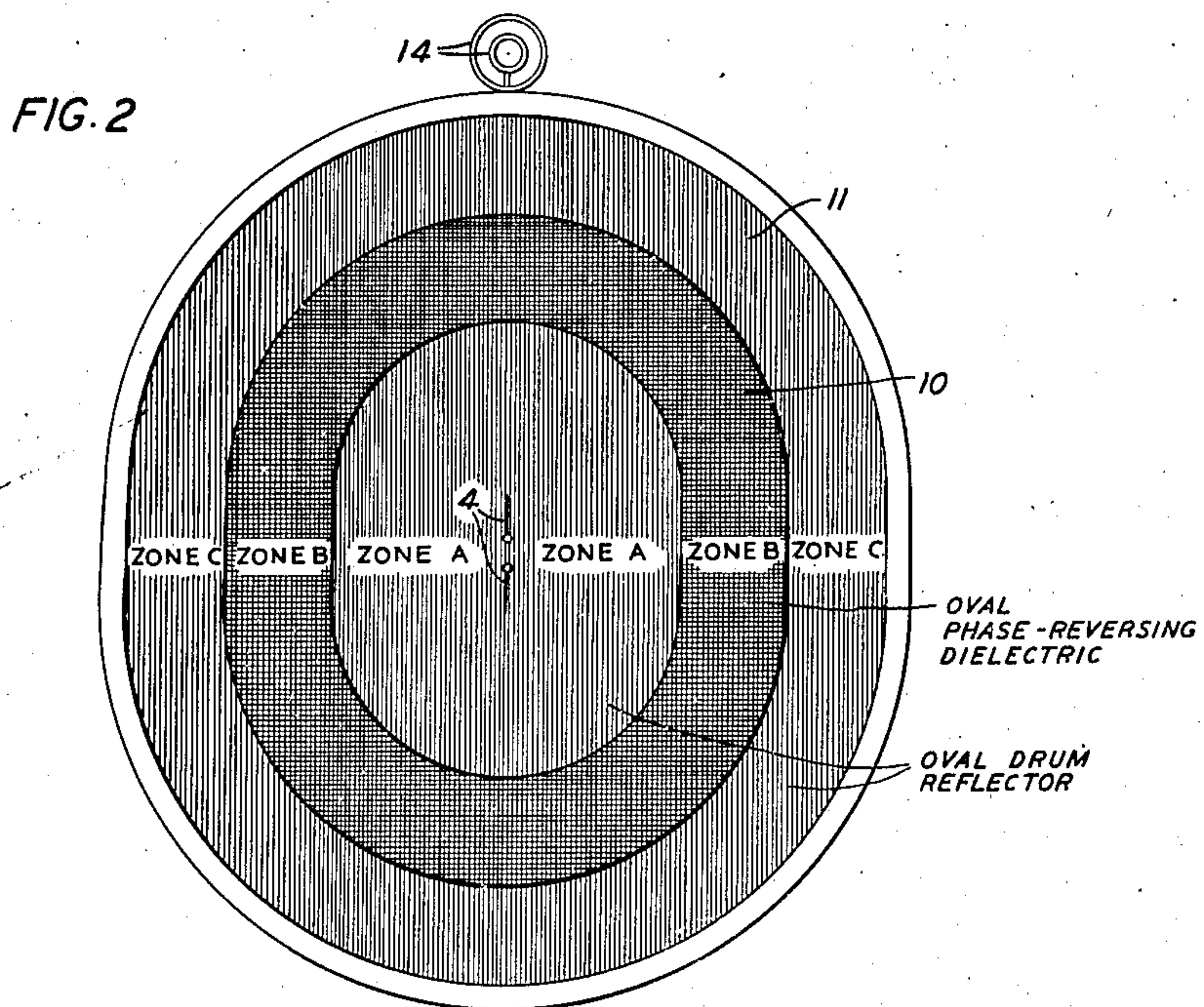
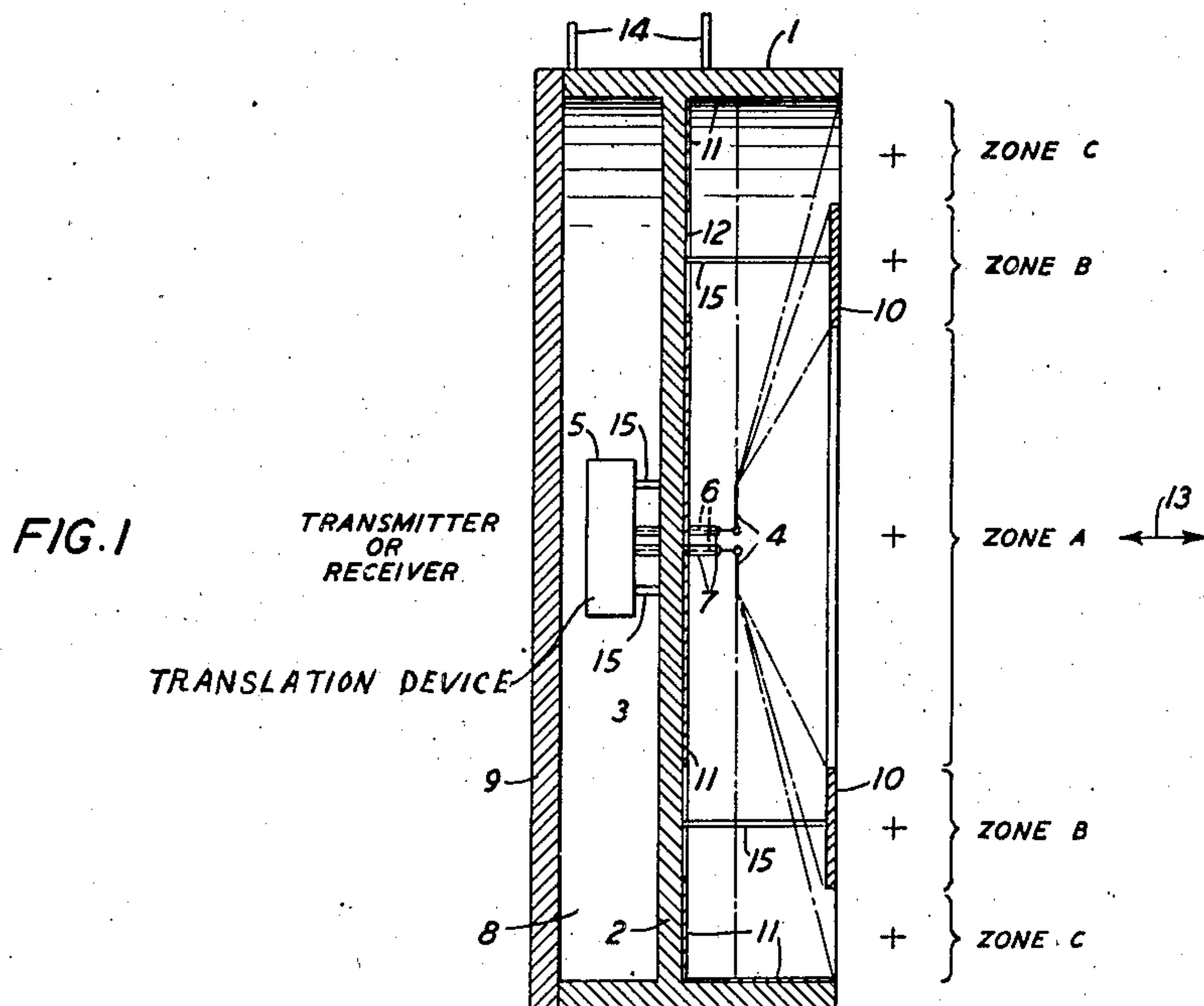
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2,412,202

DIRECTIVE RADIO SYSTEM

Filed June 28, 1941

2 Sheets-Sheet 1



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FIG. 3

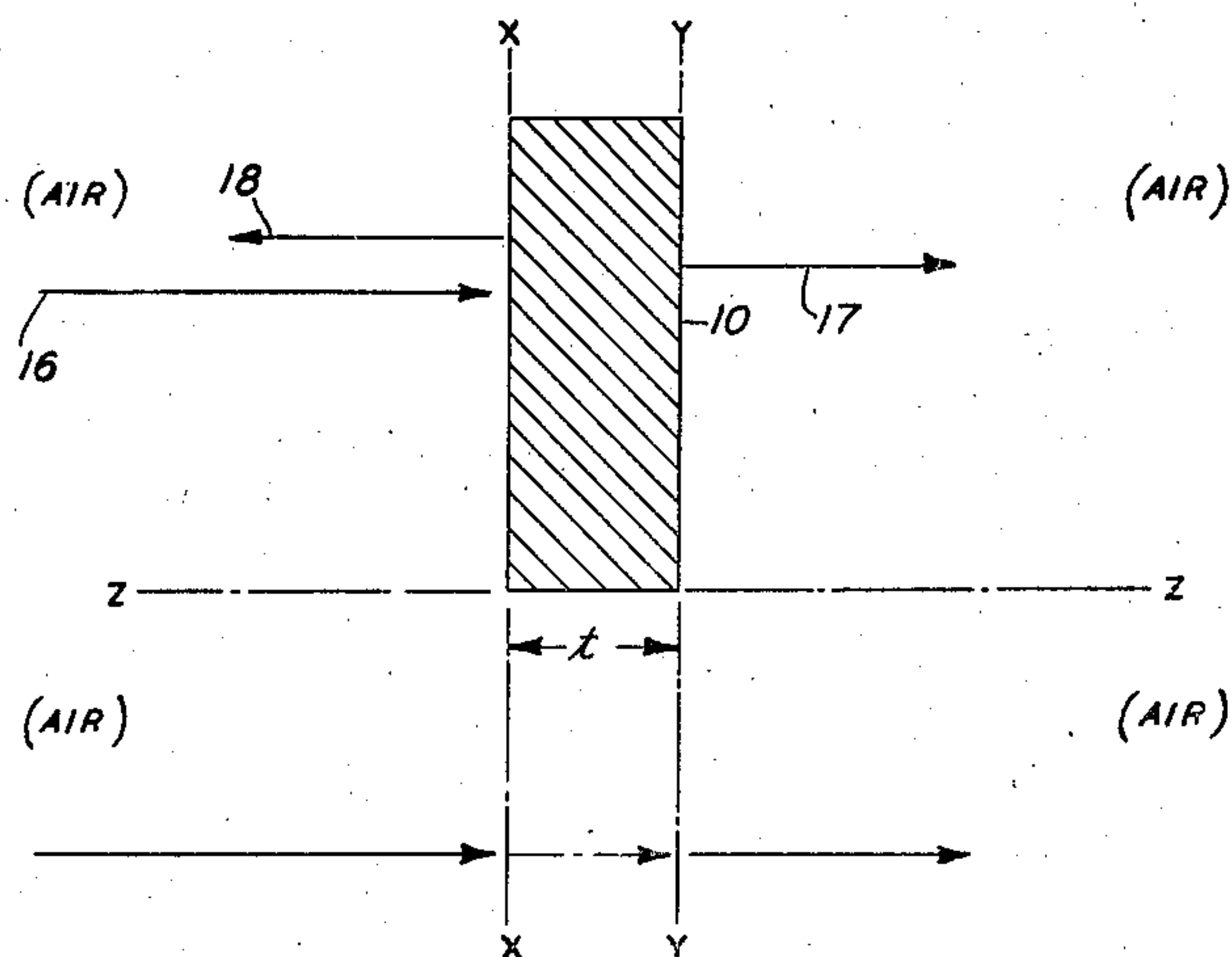


FIG. 4

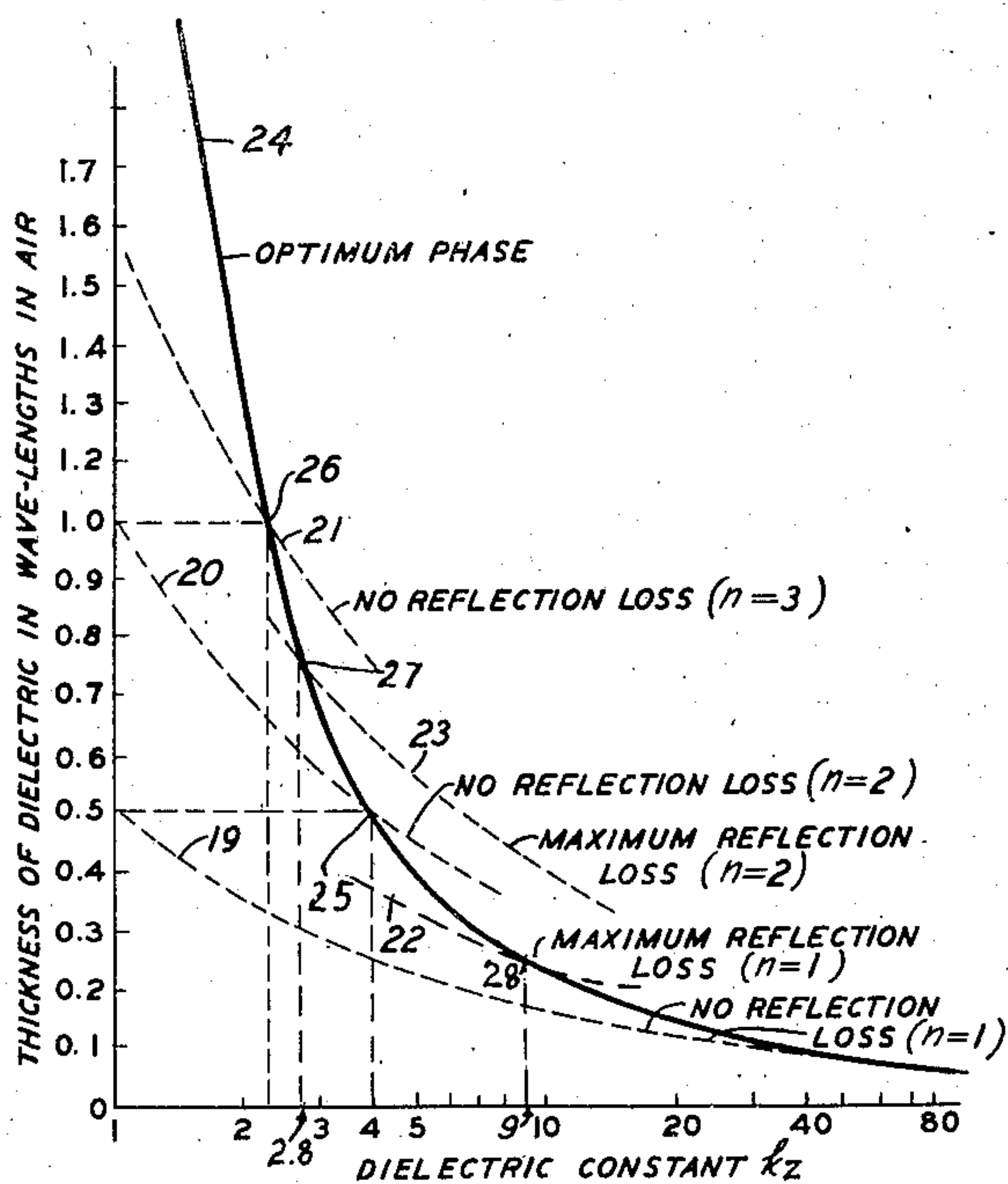
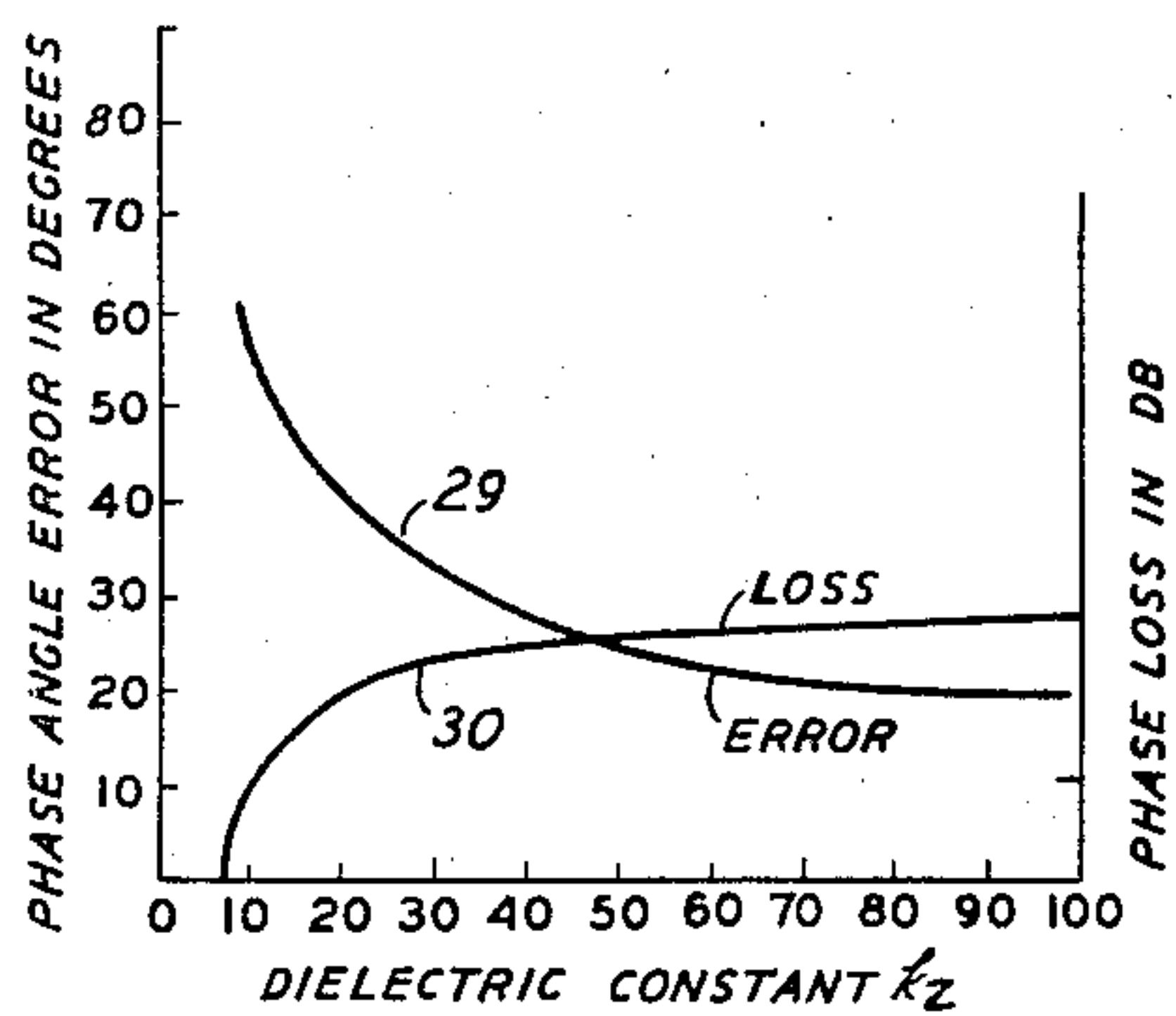


FIG. 5



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DIRECTIVE RADIO SYSTEM

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5 Claims. (Cl. 250—11)

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This invention relates to radio transmitting and receiving systems and especially to zone plates for use in short wave and ultra-short wave radiating and collecting systems.

As disclosed in my Patent 2,169,553, granted August 15, 1939, directive emission or absorption of ultra-short waves may be secured by utilizing with a half-wave doublet antenna a drum type shield-reflector having a closed reflecting end and an open end, and a zone plate positioned in the opening of the drum reflector. As explained in the above-mentioned patent, the field established in the plane of the drum opening comprises, in effect, concentric areas or zones, the field or wave components in adjacent zones being of opposite phase and the components in alternate zones being in phase agreement. The metallic or dielectric zone plate included in the system disclosed in the above-mentioned patent functions to block the propagation of one of the two sets of in-phase components whereby only in-phase components pass through the opening, the other set of in-phase wave components being rendered ineffective. It now appears desirable to utilize the last-mentioned wave components and thus enhance considerably the transmitting or receiving action of the system.

It is one object of this invention to achieve maximum unidirectivity in a radio transmitting or receiving system.

It is another object of this invention to improve the operation of quasi-optical radio transmitting and receiving apparatus.

It is still another object of this invention to utilize, in a quasi-optical system comprising a zone plate, wave components heretofore dissipated.

It is a further object of this invention to improve the operation of the drum type reflecting system disclosed in Patent 2,169,553, mentioned above.

According to one embodiment of the invention the above and other objects are accomplished by replacing the reflective dielectric or metallic zone plate forming part of one embodiment of the drum type system by a dielectric zone plate having a thickness dependent upon both the wavelength and the dielectric constant of the material of which the plate is composed. The thickness and dielectric constant are such that the

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components or wavelets passing through the plate change in phase an amount sufficient to render the wavelets of the adjacent zones in phase agreement without reflection losses. In practice, thin rather than bulky zone plates are preferred. Specifically a zone plate having a thickness of .11 wave-length as measured in air and composed of titanium dioxide set in rubber as a binder, the dielectric constant of this titanium dioxide and rubber being 20 under normal conditions, gives very satisfactory results.

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

Figs. 1 and 2 are, respectively, a sectional side view and a front view of a drum reflector having a zone plate constructed in accordance with the invention;

Fig. 3 is a sectional side view of the zone plate of the invention; and

Figs. 4 and 5 are curves which are useful in explaining the invention.

Referring to Figs. 1 and 2, reference numeral 1 designates the wall and numeral 2 the end or bottom plane reflecting plate of a drum reflector 3 of the type disclosed in my aforementioned Patent 2,169,553. A doublet 4 is positioned within the drum 3 and connected to the translation device 5 by means of line conductors 6 each of which is preferably enclosed in a coaxial shield 7. The device 5, which may be a transmitter or a receiver, is mounted on the passive side of reflector plate 2 within the compartment 8 formed by the extension of the drum 3 and by the back cover member 9. Reference numeral 10 denotes a zone plate constructed in accordance with the invention and having a thickness and a dielectric constant related to the operating wave-length. The plate 10 is, as shown more fully by Fig. 2, orbicular in shape and of such size and area as to intersect the wavelets of zone B and avoid the wavelets of zones A and C. As explained in Patent 2,169,553, the inside surface of the wall 1 and the inside surface areas of end-plate 2 facing zones A and C are veneered or lined with copper 11, the complementary or intermediate area 12 of the end-plate being left uncovered or unlined. The drum may be arranged for rota-

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tion in both the horizontal and the vertical planes and may be accurately aligned with a desired direction 13 of radiant action by means of the gun sight 14. Reference numeral 15 designates struts for rigidly associating the translation device 5 and zone plate 10 with member 2.

In operation, assuming the system of Figs. 1 and 2 is employed for receiving energy, the incoming wave propagated in a direction 13 and having a wave front perpendicular to the opening of the drum 3 passes through zones A, B and C. The wavelets in zones A and C arrive in phase at the doublet 4 inasmuch as these zones are, in effect, located at distances from the doublet differing by a wave-length. The wavelet passing through zone B is intersected, in accordance with this invention, without reflection loss by the dielectric zone plate 10 and the phase of the wavelet is delayed by the zone plate substantially 180 degrees plus the phase lag which would occur in passing through the same thickness of air, whereby the zone B wavelet arrives at doublet 4 in phase agreement with the zone A and zone C wavelets. Since each point on the path of propagation is itself a source of non-directional radiation, portions of the energies passing through zones A and C impinge upon the copper areas 11 of reflector 2 and, after reflection from the surface areas, combine at doublet 4 in phase. When used as a transmitting system the converse or reciprocal operation obtains. The wall or shield 1 effectively prevents the propagation of energy in undesired directions so that the dimensions of the minor lobes of the directive characteristic for the system are greatly reduced. The zone plate 10 functions to secure a characteristic having a higher degree of directivity than that of the system disclosed in my patent mentioned above.

Referring to Fig. 3, the method of determining the thickness of the phase reversing zone plate 10 will now be explained. Reference numeral 16 designates the propagation direction of a plane which intersects at right angles the plane XX containing one surface of the dielectric zone plate 10 and, after passing through the dielectric plate, similarly intersects the plane YY containing the other surface of the plate 10. The boundary line or surface between adjacent zones as, for example, zones A and B of Figs. 1 and 2, is represented in Fig. 3 by the line ZZ. The wavelet passing through an air zone as, for example, zone A, may be represented at the boundary plane YY by the equation

$$E_{a-t} = (E_{a-0}) \left(e^{-j \frac{2\pi t}{\lambda_a}} \right) \quad (1)$$

and the wavelet passing through the dielectric zone plate may be represented by the equation

$$E_{z-t} = (E_{z-0}) \left(e^{-j \frac{2\pi t}{\lambda_z}} \right) \quad (2)$$

where

t = thickness of dielectric zone plate and equivalent air zone.

λ_a = wave-length as measured in air.

λ_z = wave-length as measured in the dielectric zone plate.

a denotes air is the medium of travel.

z denotes the dielectric zone plate is the medium of travel.

e = the base of natural logarithm.

E_{a-0} = field strength (volts per meter) of wavelet entering air zone at plane XX.

E_{z-0} = field strength of wavelet entering dielectric zone at plane XX.

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E_{a-t} = field strength of wavelet emerging from air zone at plane YY.

E_{z-t} = field strength of wavelet emerging from dielectric zone at plane YY.

$$\lambda_z = \frac{\lambda_a}{\sqrt{k_z}} \quad (3)$$

and obviously

$$E_{a-0} = E_{z-0} \quad (4)$$

where

k_z = the dielectric constant of the plate material.

k_a = unity, and is the dielectric constant of air.

Hence

$$E_{z-t} = (E_{a-0}) \left(e^{-j \frac{2\pi t \sqrt{k_z}}{\lambda_a}} \right) \quad (5)$$

It is apparent that the thickness t affects only the phase of the waves and in order that the two adjacent waves may be a half period out of step at the secondary boundary or plane YY it is required that

$$E_{z-t} = (E_{a-t}) (e^{-im\pi}) \quad (6)$$

where m is an odd integer, including the integer 1. Substituting Equations 1 and 5 into 6 and letting m equal 1 there is obtained

$$(E_{a-0}) \left(e^{-j \frac{2\pi t \sqrt{k_z}}{\lambda_a}} \right) = (E_{a-0}) \left(e^{-j \frac{2\pi t}{\lambda_a}} \right) (e^{-i\pi}) \quad (7)$$

It follows that

$$\frac{2\pi t \sqrt{k_z}}{\lambda_a} = \frac{2\pi t}{\lambda_a} + \pi \quad (8)$$

or

$$t = \left(\frac{\lambda_a}{2} \right) \left(\frac{1}{\sqrt{k_z} - 1} \right) \quad (9)$$

Equation 9, it will be observed, expresses the relation between the wave-length in air, the dielectric constant of the material forming the plate 10 and the least thickness of the plate 10 which provides optimum phasing at the distant focus between wavelets of adjacent zones for cases where the surface reflections may be disregarded. The thickness of the dielectric material measured along the direction of wave propagation should be such that the phase lag through the material equals 180 degrees plus the phase lag which would occur in passing through the same thickness in air.

Assuming a wave 16, Fig. 3, is passing through an ordinary zone plate, an infinite number of reflections occur between the two surfaces of planes XX and YY, portions of which break through the surface and contribute to the principal transmitted wave 17 and the reflected wave 18. Since, in accordance with the present invention, the zone plate is substantially a half wave-length thick or a multiple thereof, no reflections occur at the surface. In this respect a plate 10 having the thickness mentioned above is analogous to a half wave-length lossless line or distributed impedance transformer which, as is well known, transfers unchanged the impedance at its far-end terminals to its near-end terminals. In the case of the plate 10 having a thickness t equal substantially to a half wave-length and also in the case of a thin plate having a negligible thickness, the conducting air to the right of the plate may be considered to be terminated in its intrinsic surge impedance and hence the conducting air to the left of the plate is, by reason of a half wave-length thickness of the plate,

also terminated in its surge impedance. Also, analogous to a transmission line, greatest reflection at the surface occurs for a plate thickness equal to a quarter wave-length or an odd multiple thereof. For the condition of no surface reflection, the thickness t' is given by the following equation

$$t' = (n) \left(\frac{\lambda_a}{2} \right) \left(\frac{1}{\sqrt{k_z}} \right) \quad (10)$$

and for the condition of maximum reflection the thickness t'' is given by the equation

$$t'' = (2n+1) \left(\frac{\lambda_a}{4} \right) \left(\frac{1}{\sqrt{k_z}} \right) \quad (11)$$

where n is any integer, including zero.

It will be noted from Equations 10 and 11 that for a given wave length, λ_a , the thickness varies inversely as the square root of the dielectric constant of the zone plate.

Referring now to Fig. 4, the dash-dash curves 19, 20 and 21 represent the relation between the dielectric constant, k_z , and the thickness t' , for the condition of no reflection and n in Equation 10 having, respectively, the values 1, 2 and 3. The curves 22 and 23 represent the relation between k_z and t'' , for the condition of maximum reflection and n in Equation 11 having, respectively, the values of 1 and 2. The solid line curve denoted by numeral 24 illustrates the relation given by Equation 9 for the optimum phase condition. Curve 24, it will be observed, intersects curve 20 at a point 25 corresponding to a thickness value of $.5\lambda_a$ and a dielectric constant value of 4.0, and intersects curve 21 at a point 26 having a thickness value of $1.0\lambda_a$ and a dielectric constant value of 2.2. From a practical point of view, assuming $\lambda_a = 10$ centimeters, the dielectric thicknesses of $1.0\lambda_a$ and $.5\lambda_a$, for the above dielectric values, appear to be too bulky. Hence, dielectric values of 20 and more, corresponding to a plate thickness of $.2\lambda_a$ and less, are preferred even though the optimum-phase curve 24 and the particular no-reflection curve adjacent the optimum-phase curve in the high dielectric region, that is, curve 19, theoretically do not intersect short of infinity. While, as shown by curve 24, the plate 10 may have, in so far as the phase reversing function is concerned, any dielectric constant dependent upon its thickness, a plate having a dielectric constant of 2.8 or 9.0 is the least satisfactory from a reflection standpoint since at points 27 and 28 corresponding, respectively, to these values, maximum reflection occurs. In practice it has been found desirable to tolerate the negligible phase angle error which may prevent the adjacent radiation zones from combining exactly in phase at the distant focus, and to select a plate thickness for which there are no reflections since the avoidance of reflection loss is highly desirable. Stated differently, as between reflection loss at the surface and the loss at the distant focus occasioned by a slight out-of-phase relation between the wavelets in two adjacent zones, the former is more substantial and hence should be eliminated. Curve 29 of Fig. 5 shows the phase-angle error and curve 30 the phasing loss, for plates having large dielectric constants. As shown by curve 30, the phasing loss for a plate having a dielectric constant of 10 is only 0.5 decibel.

It has been found experimentally that plates formed of materials in which titanium dioxide is an ingredient have very large, and therefore very satisfactory, dielectric constants. German "Condensa," for example, comprises titanium dioxide

and has a dielectric constant of 90. A plate comprising titanium dioxide set in rubber as a binder has a dielectric constant of 20. In a test of a system such as that illustrated by Figs. 1 and 2 and comprising a dielectric zone plate formed of titanium dioxide set in rubber and having a thickness of $.11\lambda_a$, in-phase radiations from adjacent zones were secured with a loss of only .5 decibel. This particular experiment confirmed the curves of Figs. 4 and 5. In a comparison test of two two-zone systems, one having a copper zone plate B and the other having, in accordance with the invention, a titanium dioxide dielectric zone plate B of proper dimensions, the gain of the dielectric plate system over the copper zone plate system was 5.5 decibels. In a comparison test of two three-zone plate systems, the gain of the dielectric zone plate system constructed in accordance with the invention over the copper zone plate system of the prior art was 3 decibels.

In the above it has been assumed that the wave direction is perpendicular to the dielectric surface. While this assumption may ordinarily be made in practice for greater accuracy, the thickness dimension should be measured along the wave path in the dielectric and the physical thickness of the dielectric zone plate 10 should be reduced from the critical value given herein by the cosine of the angular departure of the path from the normal path provided that the angle of departure is small. Thus, the outermost zone plates of a multiple zone antenna system may, if desired, have a thickness slightly less than the critical thickness given herein.

Although the invention has been described in connection with certain embodiments thereof, it is to be understood that it is not to be limited to such embodiments and that other apparatus and arrangements may be utilized without exceeding the scope of the invention. Moreover, while the invention has been described in connection with transverse or radio wave energy, the basic principles, including the mathematical analysis, are applicable to structures for regulating the phase and velocity of other forms of wave energy as, for example, longitudinal or sound waves.

What is claimed is:

1. A titanium dioxide radio zone plate for passing a wave of a given wave-length, said plate having a thickness of approximately .11 of said wave-length as measured in air and a dielectric constant of approximately 20, whereby the waves passing through said plate are retarded slightly more than 180 degrees and reflection losses are prevented.

2. In a wave transmission system, a dielectric flat zone plate for passing a wave of a given wave-length, said plate having a thickness equal to

$$\frac{n\lambda_a}{2\sqrt{k_z}}$$

where n is any integer, λ_a is the given wave-length and k_z is the dielectric constant of the material forming said plate, whereby reflection is prevented at the surface of said plate.

3. In a radio system, a metallic reflector, an antenna positioned at the focus of said reflector, a multiple zone plate positioned in front of said antenna and composed of titanium dioxide set in rubber.

4. In a radio system, a metallic drum comprising a tubular walled structure open at one end and having a common zone reflector, at the other end, an antenna positioned at the focus of said

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reflector and a dielectric zone plate composed of titanium dioxide set in rubber and positioned in front of said antenna.

5. In a radio system for transmitting or receiving waves having a given wave-length λ_a as measured in air, an antenna, a dielectric zone plate spaced therefrom and having a dielectric constant k , the thickness of said plate being equal to

$$\frac{n\lambda_a}{2\sqrt{k}}$$

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where n is any integer, and approximately equal to

$$\frac{\lambda_a}{2(\sqrt{k}-1)}$$

5 whereby reflection losses are prevented and the waves passing through said plate are delayed 180 degrees plus an amount equal to the shift in phase of a wave passing through an air zone of
10 similar thickness.

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