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ACHROMATIC LENS ANTENNA

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FIG. 1

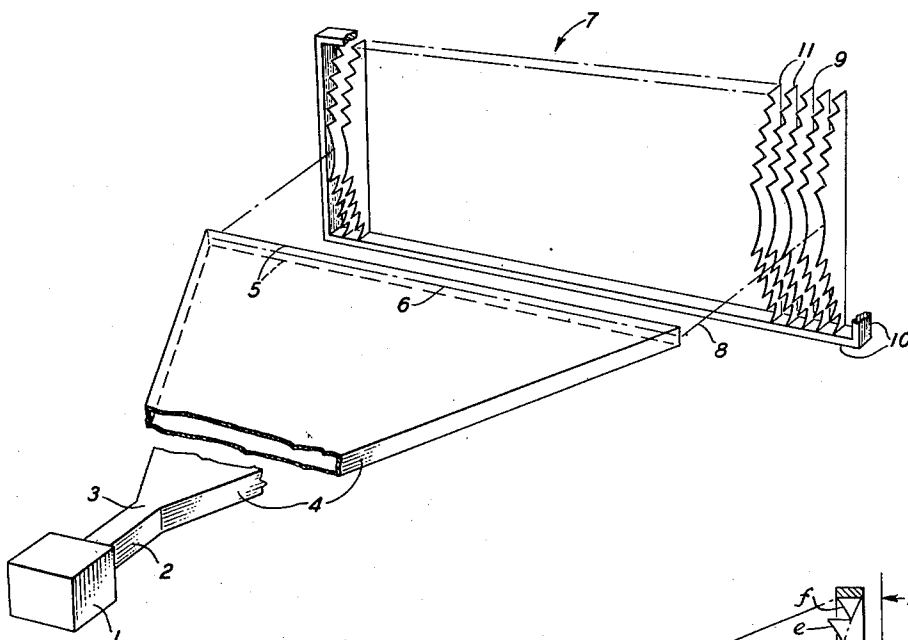
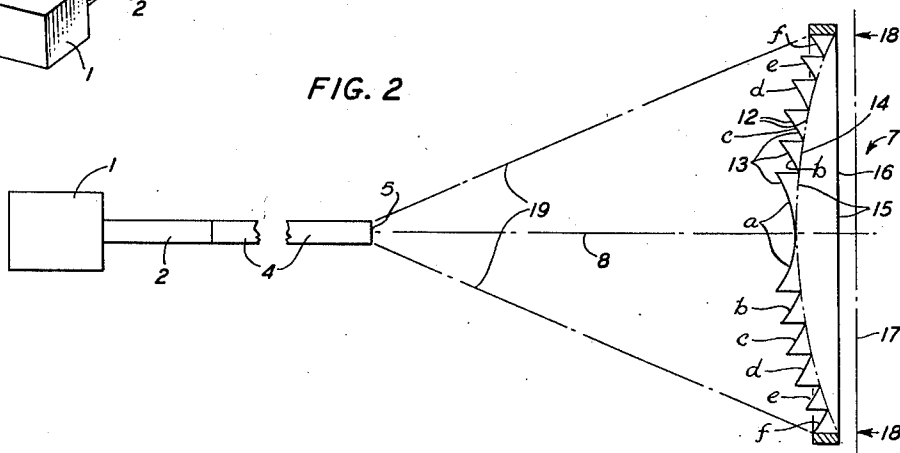


FIG. 2



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## ACHROMATIC LENS ANTENNA

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This invention relates to electromagnetic wave lenses and more particularly to a wide frequency band metallic microwave lens.

My copending application, Serial No. 642,723, filed January 22, 1946, and my article entitled "Metal Lens Antennas," published in the Proceedings of the I. R. E., vol. 34 for November 1946, at pages 828 to 836, inclusive, both disclose in identical form a multiple zone electromagnetic wave or radio "phase-advance" lens having a refractive index smaller than unity and comprising spaced parallel metallic walls. While stepping the zones of the lens increases the frequency band width over which the action of the lens is substantially uniform, as is taught in my above-mentioned application and article and is illustrated by the curves shown in Fig. 17 of the aforesaid application and Fig. 13 of the article, the increase in frequency band width is not large. To illustrate, referring to the aforesaid Fig. 17, a six-zone unstepped metallic lens having a maximum thickness of twelve wavelengths has a band of approximately 3 per cent. Stepping the zones increases the band width to approximately 7 per cent, the increase being only 4 per cent. In structures proportioned in accordance with the principles of the present invention, the band width is increased to a value in the order of 25 per cent. In accordance with the established practice of those skilled in the art, the frequency band width of a device is expressed as the percentage obtained by dividing the width of the band over which a given device performs satisfactorily in cycles by the mid-frequency of the band in cycles.

It is one object of this invention to provide electromagnetic wave lenses which will focus waves over a very large or wide band of frequencies.

It is another object of this invention to render an electromagnetic wave metallic phase-advance lens "achromatic." The meaning of the term "achromatic" as applied to structures of the invention will be explained in detail below.

It is still another object of this invention to obtain a simple inexpensive compound electromagnetic wave "achromatic" lens of simple unitary construction.

In accordance with this invention, a concave converging, that is, positive, stepped multiple zone metallic electromagnetic wave lens section of the type disclosed in my aforesaid copending application and I. R. E. article and having a given frequency band width, is in effect combined with a convex diverging, that is, negative, unstepped

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multiple zone metallic electromagnetic wave lens section having the same band width, to form a compound electromagnetic wave lens. The compound lens comprises a plurality of spaced parallel metallic plates. One side or face of the compound lens, corresponding to one side of the negative lens section, is plane and unstepped; and the opposite side or face of the compound lens, corresponding to one side of the positive lens section, is concave and stepped. By reason of the fact that one lens section is stepped and the other section is not stepped, the dispersions of the two sections are substantially different for each frequency of the electromagnetic waves having frequencies within the broad frequency band to be transmitted through the lens structure whereby an "achromatic" electromagnetic wave lens is obtained.

The term "achromatic" is employed in optics to define a lens which is "free from color" or which "refracts white light energy without decomposing it into its constituent colors." In optics an "achromatic" lens is "composed usually of two glasses, a convex and a concave, the glasses being of substances having different refractive and dispersive powers." (Quoted definitions from Webster's Unabridged Standard Dictionary.) As is well known to those skilled in the art, the various colors of lights are merely different wavelengths, or frequencies, of light energy, and an "achromatic" optical lens is, therefore, simply a lens which produces substantially uniform refraction over a broad band of frequencies of light energy. As pointed out in the introductory paragraph of my above-mentioned article, "The extension of the useful field of radio waves to the very short wavelengths has made the optical properties of such waves increasingly apparent. . . ." Inasmuch as the electromagnetic wave lenses of this invention are, in essence, composed of two portions, one portion being the equivalent of an optical convex lens and the other, the equivalent of an optical concave lens, and the two portions have different refractive and dispersive powers which mutually compensate each other to produce substantially uniform refractive effects over a broad band of electromagnetic wave frequencies, the devices of the present invention can aptly be termed "achromatic" electromagnetic wave compound lenses. Likewise, it appears entirely apt to borrow the terms "positive" and "negative" from the optical art to denote converging and diverging electromagnetic wave lenses, respectively, as has been done hereinabove. Since the lenses of the present inven-

tion are "phase advance" lenses, i. e., they speed up the wave energy passing through them rather than delaying said energy as optical glass lenses do, the physical contours of the electromagnetic wave lenses of this invention, are the inverse of the physical contours of the optical lenses. For example, a positive, or converging, electromagnetic wave lens is concave while the corresponding optical glass lens is convex.

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

Figs. 1 and 2 are, respectively, perspective and side views of a microwave system comprising a compound electromagnetic wave lens constructed in accordance with the invention.

Referring to Figs. 1 and 2, there is shown a translation device 1, such as a transmitter or receiver, connected by a rectangular wave guide 2 to the throat aperture 3 of the sectoral horn 4. The long dimension of the mouth aperture 5 of the horn 4 is aligned with a focal line 6 of the cylindrical symmetrical compound electromagnetic wave lens 7. The lens 7 has an axis or axial plane 8 and comprises a plurality of parallel identical metallic members 9 spaced apart a distance at least one-half wavelength, taken at the longest wavelength in the operating band, and held in position by means of the wooden frame 10. Each pair of adjacent members 9 and the air dielectric included therebetween constitute a channel 11 of the compound lens 7. By reason of the spacing between the adjacent members 9, the refractive index of each channel, and hence of the compound electromagnetic wave lens 7, is smaller than unity and the phase velocity of the waves passing through the lens is advanced, as explained in my aforesaid copending application and in my above-mentioned article.

As shown in Fig. 2, each of the metallic plates 9 of the electromagnetic wave lens 7 comprises in effect a section 12 having a stepped concave back side 13 and a concave front side 14, and a section 15 having a plane front side 16 and a convex back side 14, the concave front side of section 12 and the convex back side of section 15 being coincident. The circular line 14 does not necessarily represent a physical boundary between the above-described portions of the structure since it will ordinarily be more convenient to construct each plate as a unitary member, but it does denote at least, the common effective boundary of the two adjacent sections 12 and 15. The plane side 16 of section 15 and the stepped concave side 13 of section 12 constitute, respectively, the front and back faces of the compound electromagnetic wave lens 7. Since the shape of section 12 is concave-concavo, this section is, in accordance with the principles explained in my above-mentioned copending application and my I. R. E. article, a positive or converging lens section, whereas section 15 is, by the same principles, a negative or diverging lens section since the shape of this section is plano-convex. As shown on the drawing, the positive section 12 comprises the six stepped zones *a*, *b*, *c*, *d*, *e* and *f* which have different elliptical curvatures, as explained in my aforesaid copending application and my above-mentioned article. Since the lens structure is vertically symmetrical about the axial plane 8, there will be two each of the stepped zones *b*, *c*, *d*, *e*, and *f*, as shown, symmetrically spaced above and below the zone *a*. The horizontal center line of zone

*a*, of course, lies in plane 8 and zone *a* is also positioned symmetrically with respect to plane 8 as shown.

In operation, assuming device 1 is a receiver, electromagnetic waves having a frequency included in a given wide frequency band and having a plane wave front 17 and an incoming propagation direction 18, are propagated through the compound electromagnetic wave lens 7 and are focused on the mouth aperture 5 of the horn 4, as shown by the lines 19. As the frequency changes, the focal lengths of the positive and negative sections of the electromagnetic wave lens 7 vary oppositely substantially, as in the case of a compound achromatic optical glass lens when transmitting light of various colors, i. e., wavelengths or frequencies. It is because of this analogous action that the compound electromagnetic wave lens structures of the present invention are so aptly designated "achromatic." In other words, the change with frequency of the angle of convergence of a positive lens either electromagnetic wave or optical, is compensated to a substantial extent by an opposite change in the amount of divergence produced by the associated negative lens. This is obvious since the index of refraction *n* depends upon the wavelength as shown in Equation 3 of my above-mentioned copending application or Equation 2 of my above-mentioned paper. This clearly means that if the wavelength is changed to a longer wavelength, *n* becomes smaller. *n* becoming smaller means that the refractive power of the lens becomes greater so that a positive or converging electromagnetic wave lens has greater convergence and a negative or diverging electromagnetic wave lens has greater divergence.

The change in divergence of a lens is equivalent to a change in the focal length and this can be correlated with the band width of the lens. This has been done in Fig. 17 of my above-mentioned application and in Fig. 13 of my above-mentioned article. From either of these figures it is seen, for example, that the band width of an unstepped lens 6 wavelengths thick is the same as the band width of a stepped lens having 8 steps. Also, the rate of change of the refractive index with frequency, or so-called dispersion, of the positive electromagnetic wave lens is substantially different, over the given wide frequency band, from the dispersion for the associated negative lens section, by reason of the fact that the positive lens is stepped and its maximum thickness thus greatly reduced whereas the negative lens is not stepped and therefore has a relatively much greater maximum thickness. Consequently, when the two portions of the lens are properly proportioned, i. e., to have the same band width as disclosed hereinabove as the frequency varies over the wide band, the focal length of the compound electromagnetic wave lens remains substantially constant, that is, the lens is "achromatic." It may be noted incidentally that the addition of the negative lens to the positive lens increases the focal length of the combination over that of the positive lens taken alone, so that the compound lens, in one sense, corresponds to a single lens of longer focal length. It may also be added, by way of contrast, that in a compound optical lens the dispersions for the positive lens section and the negative lens sections are different not by reason of the fact that one section is stepped and the other is not, but by reason of the fact that the dielectric materials, usually

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glass, used in the two lens sections have different dispersion curves.

Although the invention has been explained in connection with a specific embodiment, it is not to be limited to the embodiment described inasmuch as other apparatus may be used in successfully practicing the invention.

What is claimed is:

1. A compound electromagnetic wave, phase advance, metallic lens for focusing waves included in a wide band of wavelengths and having a given electric polarization, said lens comprising a plurality of metallic members extending parallel to said polarization and spaced apart a distance greater than one-half the longest wavelength in said band, said lens having a stepped concave face and a plane face, said concave and said plane sides being the surfaces which include and are defined by the stepped edges and the linear edges respectively of said plurality of metallic members, the contour line comprising the base line of the steps of said concave edge of each metallic member being a smooth curve of which the linear edge of said member is a chord, whereby said compound lens comprises, in effect, a positive or converging multiple zone stepped electromagnetic wave, phase advance, metallic lens section and a negative or diverging multiple zone unstepped electromagnetic wave, phase advance, metallic lens section.

2. A compound electromagnetic wave, phase advance, metallic lens for focusing waves included in a wide band of wavelengths and which have a given linear electric polarization, said lens comprising a plurality of like flat conductive plate members arranged symmetrically in parallel planes with respect to a transverse axis normal to said plate members, said members being spaced

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at substantially equal intervals, the interval between each two successive plate members being greater than one-half wavelength of the lowest frequency of said wide band of wavelengths, each said plate member having two oppositely disposed longitudinal edges one of said longitudinal edges of each plate member being stepped and concave, the other of said edges of each plate member being unstepped, the contour line comprising the base line of the steps of said stepped edge forming with said unstepped edge a portion bounded by an arc of a circle and a chord of said arc, whereby said plurality of members form a compound lens comprising a positive, or converging, multiple zone, stepped, electromagnetic wave, phase advance, parallel plate, lens section combined with a negative, or diverging, multiple zone, unstepped, electromagnetic wave, phase advance, parallel plate, lens section, the compound lens so formed having substantially uniform refractive characteristics over a very broad band of frequencies or wavelengths.

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