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DIRECTIVE DIPLEX ANTENNA

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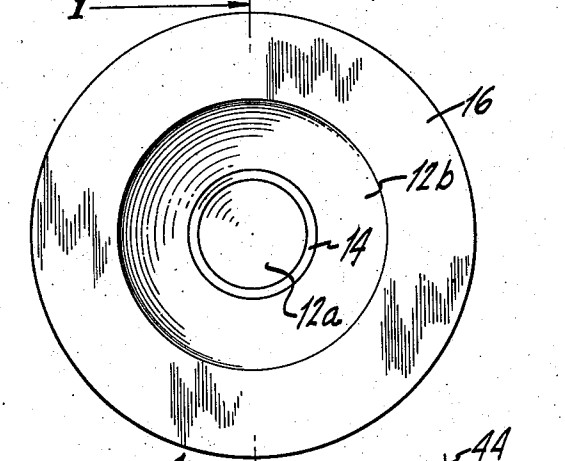
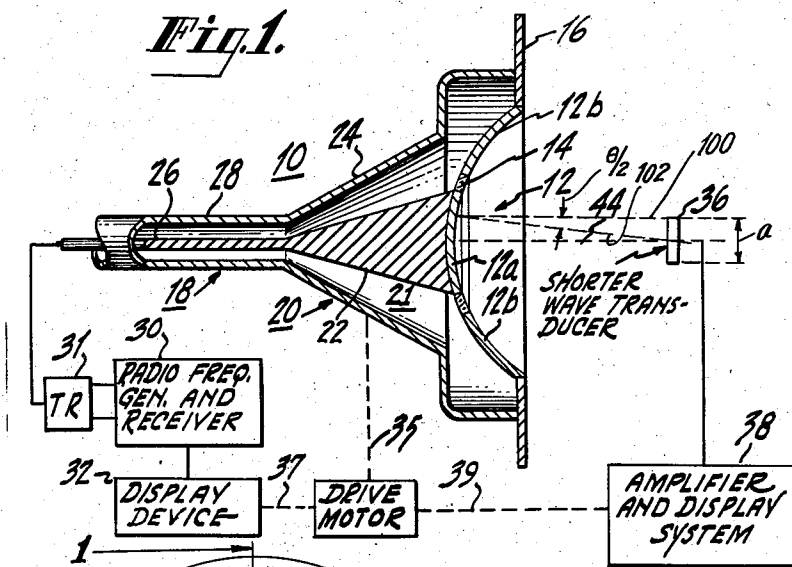
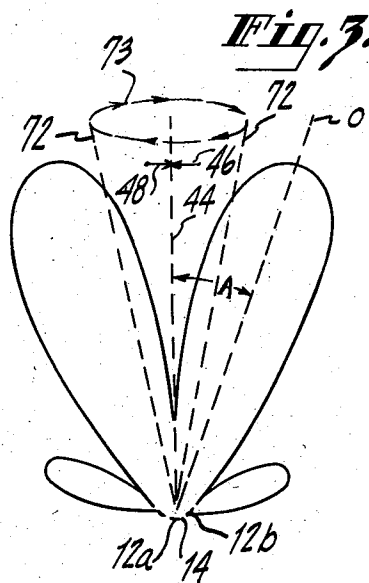
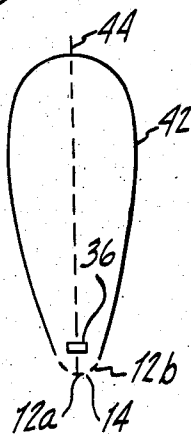


Fig. 2.



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2 Sheets-Sheet 2

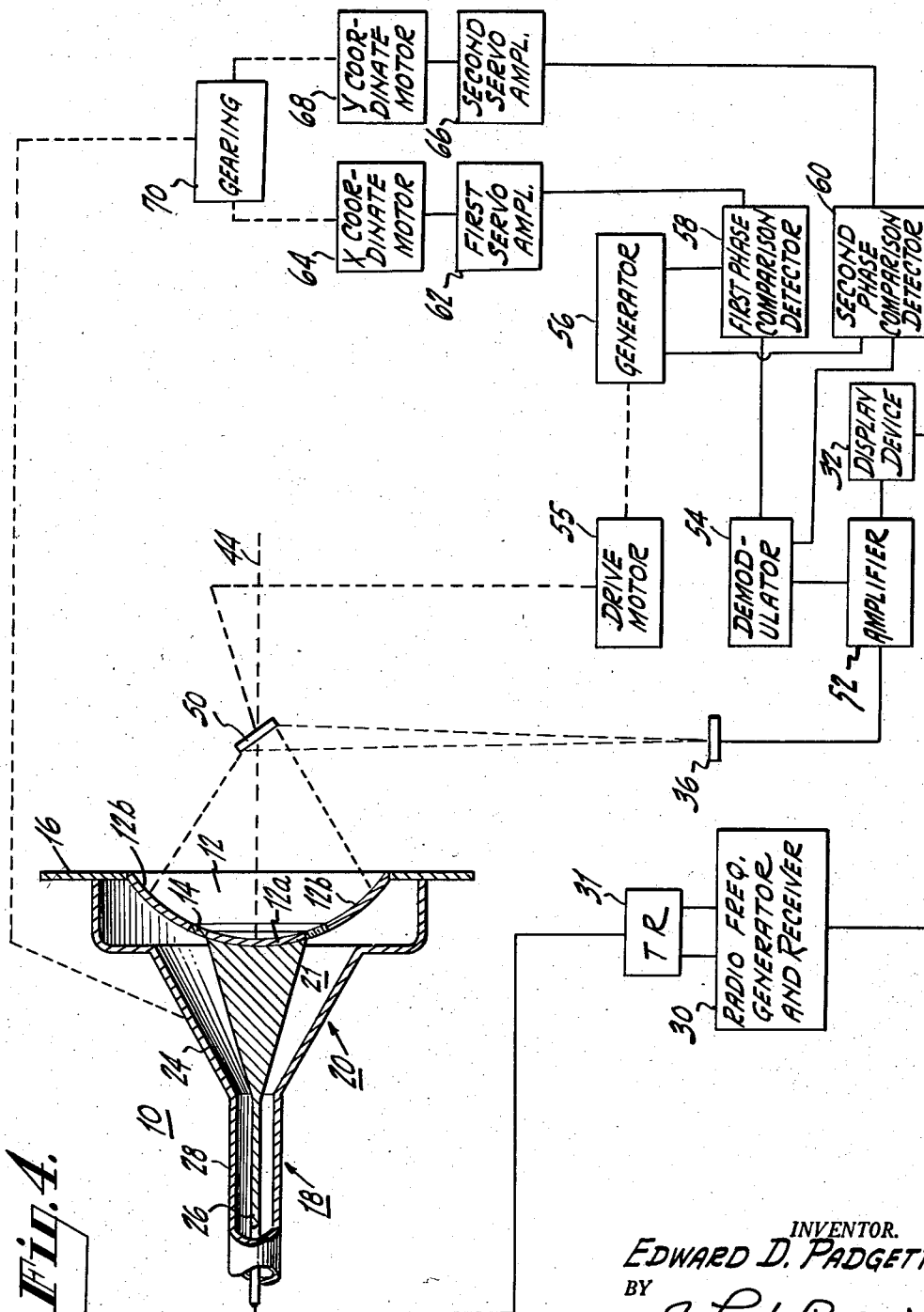


Fig. 4.

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DIRECTIVE DIPLEX ANTENNA

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12 Claims. (Cl. 343-7)

The present invention is related to wave energy radiating and/or receiving apparatus, and particularly to directive diplex wave energy apparatus.

Various types of directive antennas are well known, especially those employed in radar (radio echo detection and ranging). However, diplex antennas are customarily not employed for radar apparatus. Radar systems generally are restricted to employment of a single carrier frequency, or to the use of more than one antenna. Even in ordinary communications systems, where directive antennas are often desirable, it is not customary to use diplex antennas, because suitable directive antennas are not available.

It is an object of the present invention to provide an improved diplex radiating and/or receiving system.

It is another object of the invention to provide an improved directive diplex antenna system.

A further object of the invention is to provide an improved diplex antenna having directive properties and especially useful in radar systems.

Another object of the invention is to provide a diplex directive antenna suitable for employment at radio frequencies and light frequencies simultaneously, light frequencies being intended to include the invisible light spectrum, as it is generally understood, but to exclude ordinary radio frequencies.

In accordance with the invention, an antenna is divided into two portions which are coupled to and excited from a two-wire transmission line at one frequency, the antenna having a reflective surface suitable for reflecting energy at a second frequency of operation. In a preferred form, the antenna comprises a parabolic dish divided into an outer and inner portion by an annular cut. This dish is coupled to and excited from a coaxial line which has its inner conductor connected to the central portion of the element thus divided, and its outer conductor connected to the outer portion of the dish. The dish is reflective for energy in the infra-red region (including portions of the microwave spectrum that lie adjacent to the infra-red region), or if desired, in the region of the visible spectrum. Accordingly, a light-sensitive element at the focus of the dish may be employed for directive light reception, and a receiver and/or transmitter connected to the coaxial line may be employed for directive reception and/or transmission at radio frequencies.

The foregoing and other objects, advantages, and novel features of the invention will be more fully described in connection with the accompanying drawing in which like reference numerals refer to similar parts, and in which:

Fig. 1 is a diagram schematically portraying a system employing an antenna according to the invention, the antenna being illustrated in cross-sectional view taken along the section line I-I of Fig. 1a;

Fig. 1a is a front view of the antenna shown in Fig. 1;

Fig. 2 is a diagram schematically illustrating the direc-

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tional characteristics of the antenna of Fig. 1 for infra-red energy, that is, the shorter wave-length energy;

Fig. 3 is a diagram schematically portraying the directive characteristics of the antenna of Fig. 1 for radio-frequency energy; and

Fig. 4 is a diagram schematically portraying another radar system employing an antenna according to the invention and shown in cross-sectional view, and in which the focal point for infra-red energy is displaced from the axis of the dish.

Referring to Figs. 1 and 1a, the antenna 10 includes a polished metallic dish 12 divided into a central portion 12a and an outer portion 12b by an annular slot 14 which may be filled with a suitable dielectric such as Teflon. The rim of the dish 12 may be joined to an annular plate 16 of metal which may serve as a ground plane. A coaxial line 18 is connected to the antenna 10 by a transition section 20 having an inner conductor portion 22 and a coaxial outer conductor portion 24 each of which grows larger in diameter progressing from the coaxial line toward the dish 12. At its larger diameter end, the transition section inner conductor 22 is connected to the inner dish portion 12a. The outer conductor portion 24 at its larger diameter end is connected to the ground plate 16. If desired, the ratio of the inner diameter of the outer conductor portion 24 to the outer diameter of the inner conductor portion 22 may be kept constant, to keep the characteristic impedance of the transition constant and the same as the characteristic impedance of the coaxial line 18. In such case, the spacing 21 between the inner and outer conductors of the transition section gradually increases from the coaxial line 18 to the dish 12. At the small diameter ends, the outer conductor portion 24 and the inner conductor portion 22 are connected respectively to the outer and inner conductors 28 and 26 respectively of coaxial line 18.

The coaxial line 18 is connected to a radio-frequency generator and/or receiver 30 which may be connected to a suitable display device 32. A drive motor 34 may drive the antenna and its mounting (not shown) and the display device in a suitable scan, as indicated by the dash lines 35, 37.

A transducer element 36 or plurality of such elements, for example of the kind employed for the detection of infra-red radiation, is mounted at or near the focal point of the preferably paraboloidal surface of the dish 12. The element 36 may be any of the elements known for deriving an electrical signal in response to the radiation to be detected. For example, the element 36 may include a photo-conductive material such as a semi-conductor, or a lead sulfide and thallous sulfide cell, or it may include a photo-electron emissive cell or tube. It is not essential that the element 36 respond to infra-red radiation. Under certain circumstances, the element 36 may be a dipole or the like responsive to a radiation of substantially shorter wave length than that to be received or transmitted through the slot 14. The element 36 is connected to an amplifier and display system 38, to which the drive motor 34 may be mechanically or electrically connected or coupled as indicated by the dash line 39.

In operation, the dish 12 together with the element 36 has a directive radiation pattern which may be represented by the lobe 42 of Fig. 2. There also may be side lobes (not shown). The axis of the lobe 42 is coincident with the axis 44 of the dish 12. The pattern 42 displayed is in a plane including the axis 44. As understood in optics, as long as the reflective area of the dish 12 has dimensions large compared to a wave length of the radia-

tion at the operating frequency to be detected or radiated from the element 36, the aperture of 14 will have little or no effect on the radiation pattern 42, except to somewhat reduce the total intensity of the radiation. The paraboloidal dish has an inherently high gain for the shorter wavelength radiation. For the longer wavelength radio frequency energy, the slotted device effectively matches the impedance of free space, namely 377 ohms, with a nominal gain.

Referring again to Figure 1, the size of element 36 should preferably be substantially smaller than that of parabolic dish 12. The angle $\theta/2$ between an incident ray 100 from a distant object which passes adjacent one edge of element 36 and the reflected ray 102 which passes through the focus of the dish should be sufficiently small that $\tan \theta/2 \approx \theta/2$. In such case $\tan \theta/2 = \theta/2 = a/2f$, or $a = \theta f$, where a is the length of element 36 and f is the focal length of the parabolic dish.

The radiation pattern at the lower frequency supplied by the transmission line 18 may be understood by reference to Fig. 3. In Fig. 3, the pattern is shown in a plane including the axis 44. Except for irregularities introduced by elements such as the leads to member 36 and the like, which are not intentionally introduced, the radiation pattern will be symmetrical about the axis 44, and viewed in any plane including the axis 44 is the same. The energy pattern, although drawn as two lobes for purposes of illustration, in reality has maximum intensity points along a conical surface symmetrical about 44 originating at the dish, and having a solid apex angle $2A$. Considering the energy from the right-hand left-hand sides of the annular slot 14, as viewed in Fig. 3, at a distance along the axis 44, because of the symmetry of the figure, it is apparent that if a field strength having an electric vector such as 46 is viewed from, say the right-hand side of the slot 14, then an electric vector such as 48 instantaneously represents the field strength arising from the left-hand side of the slot 14. Therefore, as viewed from this point along the axis 44, the vectors 46 and 48 subtract from each other so that the net field strength along the axis is zero. Next, the approximation is readily derived for the angle at which a maximum is found as measured from the axis 44. Let this angle be A . Along the line an angle A from the axis 44 let the point at which the field is to be considered be O . If the distance of O from the antenna 10 is very great, then to a first approximation, the radiation from the left-hand side of the slot (see the point O as drawn in Fig. 3) has reversed in phase, when A is an angle such that the distance s divided by the diameter of the annular slot 14 is equal to a half wavelength at the operating frequency (the lower operating frequency). This is readily apparent from the geometric construction as shown in Fig. 3. Although the cancellation or subtraction of the vectors along the axis 44 to be zero is geometrically obvious, it is not so obvious that the angle A is equal to $\lambda/2D$, where D is the diameter of the annular slot 14 and λ is the operating wavelength at the lower frequency. In fact, one should take into consideration contributions from all of the portions of the annular slot 14, which in this case do not cancel each other and must be suitably integrated. Nevertheless, the fact that angle A as the angle from the axis 44 at which maximum radiation is to be expected, is the angle whose sine is $\lambda/2D$ may be expected to be a fair first approximation where the slot width and slot dimensions are not large with respect to a wavelength.

If desired, the principal angle A may be brought quite close to the axis by making the diameter D of the annular slot 14 rather large with respect to a wavelength. However, this involves the addition of side lobes, as shown, and cannot be carried too far. It is also to be understood that the antenna of Fig. 1 may be designed to provide a very steep drop in radiation intensity along axis 44. In such case, an "on-target" response will be indicated by a null or sudden drop in intensity of a received signal.

Returning now to Fig. 1, the radio-frequency generator and receiver 30 may include separate units which are connected during transmit periods to the transmission line 18 by a T-R (transmit-receive) switch 31. The T-R switch 31, as is known, automatically connects the generator during transmit periods to the transmission line 18 and effectively disconnects the receiver. During non-transmit periods, the receiver effectively is connected to the transmission line 18 and the generator effectively is disconnected. The generator may be pulsed at periodic intervals, as known in radar, and received signals may be displayed on a display device 32. The drive-motor 34 may be mechanically or electrically (not shown) connected or coupled to the display device 32 to correlate echos received with the instantaneous position of the axis 44. At the same time, the range or distance of the reflecting object from the antenna 10 may be indicated on the display by its distance along a sweep of an electron beam of a cathode ray oscilloscope radar indicator. These systems of display are well known, and need not be further described. At the same time, by turning the element 36 at an appropriate angle, a response at the higher frequency may be obtained along the axis 44 of the reflector. Another way of securing such a response, is to displace the element 36 radially from the axis 44. In either event, the display of the object radiating infrared radiation or the like, as detected by the element 36, may be displayed after amplification in the amplification and display unit 38. Such display may be correlated with the display 32 connected to the radio-frequency generator and receiver 30 by mechanical connection to the drive-motor 34.

Referring to Fig. 4, a radio frequency transmitter and receiver 30 is connected to the transmission line 18 through a T-R switch 31, as before. A reflector 50 may be suitably positioned at or near the focal length of the dish 12 in order to reflect energy to a displaced focal point at which the element 36 is positioned. The element 36 is connected to an amplifier 52 which is connected to the display 32. A drive-motor 55 may drive the mirror 50 in a nutating motion, with or without precession, with the result that the pattern (illustrated in Fig. 2) of the higher frequency radiant energy also nutates. Nutation of the pattern of Fig. 2 causes an apparent modulation of any off-axis targets, or radiating objects not located on the axis of nutation. The apparent modulation is demodulated in a demodulator 54. A generator 56 driven by the drive-motor 55 provides a signal of one phase at the frequency of nutation and a second signal at the same frequency displaced by 90 degrees from the first nutation signal. The first nutation signal is applied to a first phase comparison detector 58, and the second nutation signal is applied to a second phase comparison detector 60. The demodulator 54 is connected to each of the phase comparison detectors. The first-phase comparison detector derives a voltage having a sense and amplitude corresponding to the departure in phase of the demodulated signal from generator 56. Similarly, the second-phase detector 60 derives a signal corresponding in sense and amplitude to the departure in phase of the demodulated signal from the second signal from generator 56. The output of the first-phase comparison detector 58 is applied to a first servo amplifier 62 which controls the sense of an x-coordinate motor 64. A second servo amplifier 66 receives the output of the second-phase comparison detector 60 and controls the rotation of a y-coordinate motor 68 after amplification in the second servo amplifier 66. The two motors, that is the x- and y-coordinate motors, and the gearing 70 they drive control the position of the antenna as an entirety about two coordinate axes, which may be designated as x and y axes (not shown), normal to the axis of the dish 12.

In operation, the axis about which the nutation is performed of the higher frequency radiation pattern lies on

the axis 44. Such motion may be circular, for example, in which case the high frequency pattern moves along a conical surface indicated in Fig. 3 by dashed lines 72 and arrows 73. In that event, if the target or reflecting object is not on axis 44 but is to one side or the other of it, the returned signal has a modulation at the frequency of the nutation due to the target finding itself alternately nearer a higher or a lower value of the higher frequency directivity pattern.

Although in the example above the nutating motion of the mirror is described as being circular it should be appreciated that this motion may have other forms. In each case, however, it is necessary that the nutating beam pattern be symmetrical about axis 44 so that when the antenna is "on target" for the higher frequency (light or infra-red radiation) nutating pattern, it is also "on target" for the lower frequency (microwave or the like) stationary conical beam pattern. It will be obvious to those skilled in the art that in the event detector element remains stationary the nutating motion imparted to mirror 50 must be such that the light beam reflected by mirror 50 remains focused on the detecting element. It will also be apparent that the condition of focus may be maintained by mechanically connecting the mirror to the detector element 36 so that the spacing of the two elements and the angle between the elements remains the same. In such case drive motor 55 simultaneously moves both mirror and detecting element.

In the discussion above and the one which follows, mirror 50 and detector 36 are described as being receiving elements. It will be understood by those skilled in the art that the system operates equally as well as a transmitting system. In such case, a local source of high frequency energy such as light is directed at the mirror and the light is reflected by the mirror to the surface of antenna 10 to the target.

The modulation introduced due to the nutation when a target is not on the axis 44 of nutation may be recovered by any suitable demodulator 54. It may be assumed that the demodulator 54 includes amplification as desired. Any of many known phase detectors may be employed for the first and second phase comparison detectors 58 and 60. An example of a generator 56 and phase detectors 58 and 60 suitable for employment in the arrangement of Fig. 4 are those of the radar set known as the SCR584 (a U.S. Army designation) used in the antenna-positioning circuits of that set. The phase detectors used in the SCR584 are of a commutating type. Briefly, as in the SCR584 arrangement, the reference voltage from the generator 56 to the first phase comparison detector 58 may be adjusted to provide an error signal to which the first servo motor or x-coordinate motor 64 is responsive. Two double triodes are provided as commutator tubes, each having first and second sections. Each double triode has its grids driven in push-pull by the error signal. One double triode has a common cathode resistor for its cathodes, as also does the other double triode. Cathode resistors are joined and may be grounded at their junction. Each double triode has its anodes driven in push-pull by one reference voltage from the reference generator 56 which is first squared. The connections are such that when one double triode grid voltages are in phase with the anode voltages the other double triode grid voltages are out of phase with its anode voltages. It is readily shown that for voltages and the grids in phase or 180 degrees out of phase with the error voltage, one or the other cathode resistor has more current through it than the other, but for voltages on the triode grids phased 90 degrees from a reference voltage, the voltages across the cathode resistors are balanced. The differential voltage across the two cathode resistors is filtered, amplified, and used to control the direction and magnitude of current driving a motor, which corresponds in this case to the x-coordinate motor 64. This differential voltage has sensing, the voltage across one resistor

being greater than that across the other and vice versa according to whether there is a component in phase or out of phase with the reference voltage on the grid of one of the double triodes. The first phase detector 58 output (the differential voltage mentioned) is used as an error voltage for the first servo amplifier 62 and x-coordinate motor 64. In the SCR584 circuit the servo amplifier 62 takes the form of a D.-C. (direct current) amplifier including an amplidyne. The x-coordinate motor 64 is a D.-C. motor receiving the current output of the amplidyne.

The arrangement of phase detector 60 and servo amplifier 66 may be similar to that of the first phase detector 58 and the first servo amplifier 62, respectively. The second servo amplifier 66 controls the second or y-coordinate motor 68 which brings the axis 44 of nutation into alignment with the reflecting or radiating target. It is apparent that the action of the two servo loops, when the connections are made in the proper sense, will bring the axis 44 of nutation into alignment with the reflecting object or radiating object giving rise to the modulation. The servo amplifiers 62 and 66 and the motors 64 and 68 may also take the form of the D.-C. amplifiers (including amplidynes) and motors used for antenna positioning in the SCR584. Anti-hunt and other auxiliary circuits may be provided similarly if desired.

It will be apparent to those skilled in the art that other suitable phase detector, amplifier, and motor arrangements than the one here specifically discussed may be employed. The choice of components may well depend on the frequencies involved, the load to be positioned, and other factors of an engineering nature. For example, the x- and y-coordinate motors 64 and 68 may each be a two-phase motor. It should, therefore, be understood that the connections, especially to the motors, are purely schematic, and not intended to show in detail all of the various wires and connections which might be employed in any practical case. Such connections and wiring will, however, be well understood by those skilled in the servo or electrical motor arts.

Thus the target is centered upon the axis of nutation automatically. In other words, the antenna 10 is automatically positioned in azimuth and elevation so that the axis of nutation 44 is directed at the radiation-reflecting object or target which reflects radiation at the frequency of the transmitter-receiver 30. At the same time, the element 36 receives electrical signals from the target viewed and these are amplified in the amplifier 52 and applied to the display 32. Signals from the element 36 may be displayed on twin trace cathode ray tubes or on the same oscilloscope, for example, as targets from the transmitter-receiver 30. If desired, they may be displayed in a different color, by known techniques, one display superimposed on a map-like area and the other display likewise superimposed on the same area, but the signals from one in one color and the signals from the other another color. Accordingly, it is readily determined, for example, whether the target being automatically tracked and whose range is known and may also be displayed is the same target as the one returning or radiating infra-red radiation. It will be apparent that there are many uses for an antenna such as the antenna 12 having a directivity pattern in two distinct frequency spectrums of electromagnetic radiation.

The invention thus described provides an antenna having a directive pattern in two different operating frequencies or operating frequency ranges of the electromagnetic energy spectrum. In a preferred form, the antenna includes a polished dish having an annular slot filled with a dielectric substance. The dish is driven to radiate energy from the slot by a coaxial transmission line having inner and outer conductors connected respectively to the central and outer portions of the dish into which the annular slot divides it. Thus for the lower frequency, the dish is divided into two sections which are

driven by radiated or received energy as a two-conductor antenna. The polished dish is utilized for higher frequency radiation as a reflective antenna having a point or a region of focus at which may be located an element or plurality of elements responsive to the higher frequency radiation.

What is claimed is:

1. In combination, a directive antenna comprising a concave reflecting member having a focal point and formed with a center conducting portion, an outer conducting portion surrounding said center conducting portion, and a dielectric insulating portion located between and joining said center and outer portions; a transmission line one conductor of which is connected to said center conducting portion and another conductor of which is connected with said outer conducting portion; and means at said focal point for receiving waves reflected from said reflecting member.

2. In combination, a directive antenna comprising a member formed with a paraboloidal reflecting surface having a center conducting portion, an outer conducting portion surrounding said center conducting portion and an annular dielectric member located between and joining said center and outer portions; a transmission line one conductor of which is connected to said center conducting portion and another conductor of which is connected to said outer conducting portion for conducting electromagnetic energy in one frequency range; and means at the focus of said paraboloidal reflecting surface for receiving waves reflected from or applying waves to said paraboloidal reflecting surface in another frequency range.

3. A directive antenna system comprising a member formed with a paraboloidal reflecting surface having a center conducting portion, an outer conducting portion surrounding said center conducting portion and an annular dielectric member located between and joining said center and outer portions; a coaxial line for conducting electromagnetic energy; an impedance matching section joining said coaxial line to said member comprising a cone-shaped conducting member joined at the smaller end thereof to the center conductor of said coaxial line and at the larger end thereof to said center conducting portion about the periphery of said center conducting portion, and an outer member concentric with said cone-shaped member joined at the smaller end thereof to the outer conductor of said coaxial line and at the larger end thereof to the outer peripheral edge of said outer conducting portion; and a wave receiving element located at the focus of said reflecting surface for receiving waves reflected from said surface.

4. A directive wave energy radiator-receiver comprising a member formed with a paraboloidal reflecting surface having a center conducting portion, an outer conducting portion surrounding said center conducting portion and an annular dielectric member located between and joining said center and outer portions; a two conductor transmission line, one of said conductors being coupled to said center portion and the other of said conductors being coupled to said outer portion, said transmission line serving to conduct electromagnetic wave energy at a given frequency; wave receiving means at least one portion of which is located at the focal point of said paraboloidal reflecting surface; and transmission means for conducting electromagnetic wave energy of a frequency at least several times that of said given frequency, connected to said wave receiving means.

5. A directive wave energy radiator-receiver as set forth in claim 4 wherein said portion of said wave receiving means at said focal point comprises a mirror.

6. A directive wave energy radiator-receiver as set forth in claim 4 wherein said wave receiving means includes a wave detector element.

7. A directive wave-energy radiator-receiver as set forth in claim 4, and further including means connected

to said wave receiving means for nutating said wave receiving means about the center axis of said paraboloidal reflecting surface.

8. A directive wave energy radiator-receiver as set forth in claim 6 wherein said wave detector element is located at said focal point.

9. A directive wave-energy radiator-receiver as set forth in claim 7, and further including signal responsive means connected to said wave receiving means through said transmission means for deriving therefrom a control signal having a parameter the amplitude of which is a function of the displacement of a target transmitting a signal at said second frequency from the center axis of said paraboloidal surface; and means coupled to said signal responsive means and to said member having said paraboloidal reflecting surface for moving the latter so as to cause said center axis thereof to intersect said target.

10. A directive wave-energy radiator-receiver comprising a member formed with a paraboloidal reflecting surface having a center conducting portion, an outer conducting portion surrounding said center conducting portion and an annular dielectric member located between and joining said center and outer portions; a coaxial line for conducting electromagnetic energy; and an impedance matching section joining said coaxial line to said member comprising a cone-shaped conducting member joined at the smaller end thereof to the center conductor of said coaxial line and at the larger end thereof to said center conducting portion about the periphery of said center conducting portion, and an outer member concentric with said cone-shaped member joined at the smaller end thereof to the outer conductor of said coaxial line and at the larger end thereof to the outer peripheral edge of said outer conducting portion; light ray detector means; a mirror located at the focus of said element having a paraboloidal reflecting surface for reflecting light rays received by said surface onto said light ray detector means; drive motor means mechanically connected to said mirror for nutating said mirror about the center axis of said element having a paraboloidal surface while maintaining said mirror focused at said light ray detector means, whereby a target directing light at said paraboloidal surface which is not on said center axis causes said mirror to focus on said light ray detector element a signal of varying amplitude; and a means coupled between said light ray detector element and said antenna and responsive to a parameter of said signal for moving said antenna so that its center axis intersects said target.

11. A directive wave-energy radiator-receiver system comprising, in combination, a reflector element formed with a paraboloidal reflecting surface having a circular center conducting portion, an annular outer conducting portion surrounding said center conducting portion, and an annular dielectric portion located between and joining said center and outer portions, said reflecting surface having a center axis passing through the focal point of said reflecting surface; a coaxial transmission line having a center conductor and an outer conductor; an impedance matching section having a conical inner member and a conical outer member spaced from said inner member, the smaller end of said inner and outer members being joined to the center and outer conductors respectively of said coaxial transmission line and the larger ends of said inner and outer members being joined to the center and outer conducting portions of said reflecting element respectively, said coaxial line being adapted to conduct electromagnetic wave energy at a given radar frequency to and from said reflecting element.

12. A system as set forth in claim 11, and further including a light ray detector; a mirror located at said focal point and positioned to reflect light rays transmitted by a remote target to said reflecting surface from said reflecting surface to said light ray detector; means mechanically coupled to said mirror for nutating said

mirror in a symmetrical manner with respect to said center axis while maintaining the light received thereby directed at said light ray detector, whereby when said target is displaced from said axis said mirror receives and reflects a signal of varying intensity as it is nutated with respect to said axis; and means electrically coupled to said light ray detector and mechanically coupled to said reflector element responsive to the intensity of light received by said detector for moving said antenna to cause its center axis to intersect said target.

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