

April 29, 1952

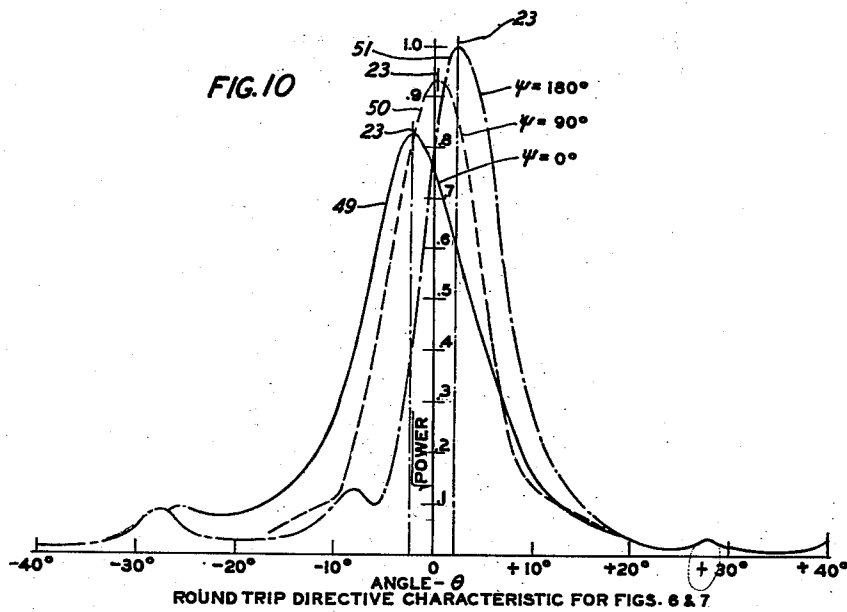
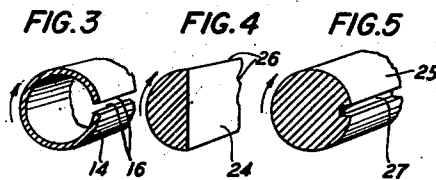
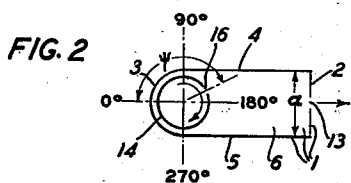
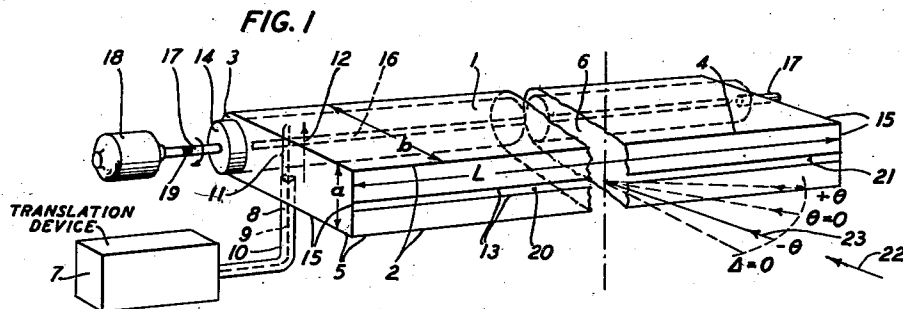
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2,594,409

DIRECTIVE ANTENNA

Filed July 27, 1943

3 Sheets-Sheet 1



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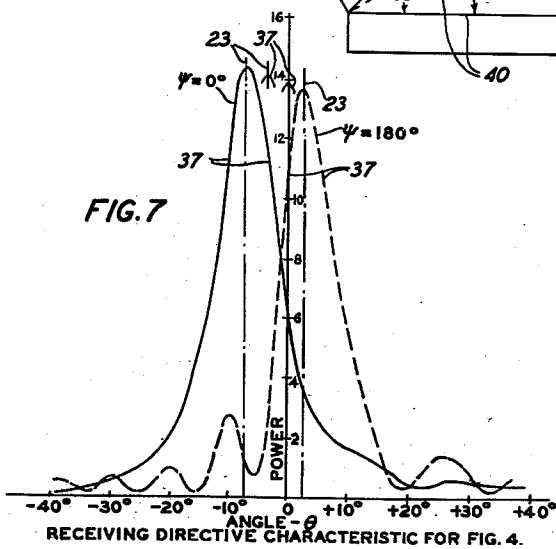
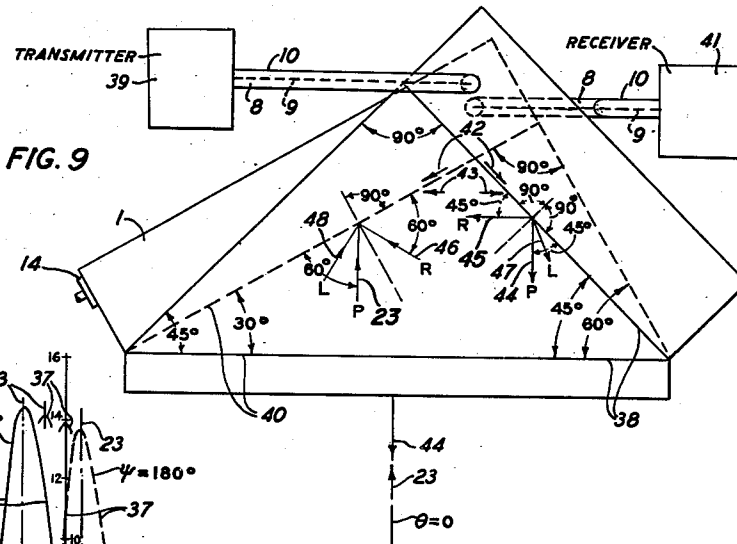
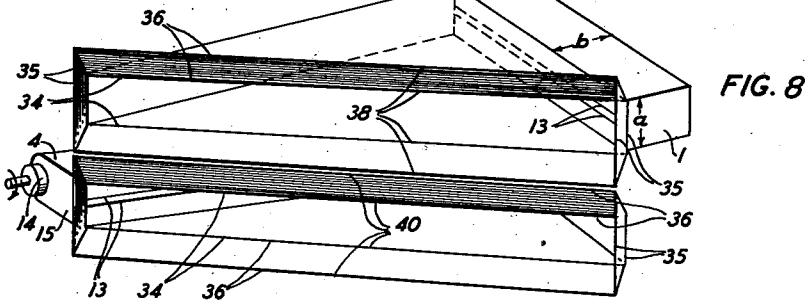
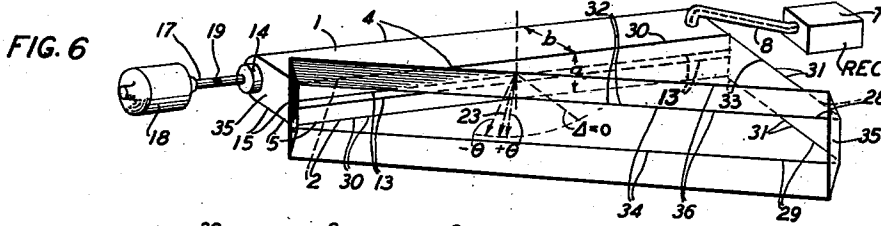
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DIRECTIVE ANTENNA

2,594,409

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3 Sheets-Sheet 2



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DIRECTIVE ANTENNA

2,594,409

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3 Sheets-Sheet 3

FIG. 11

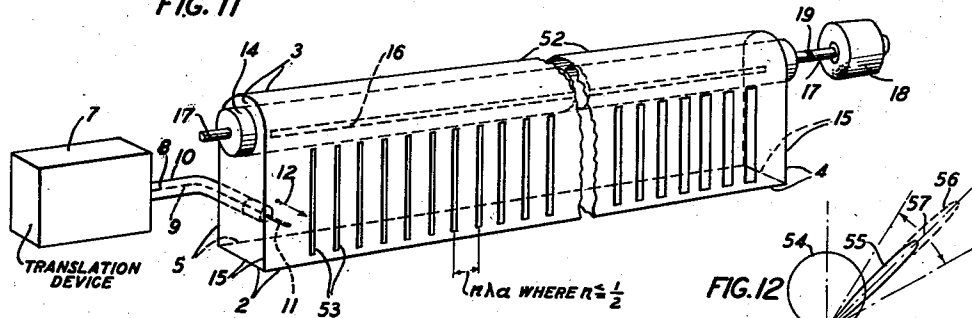


FIG. 13

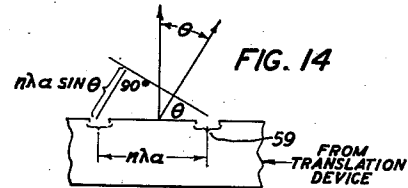
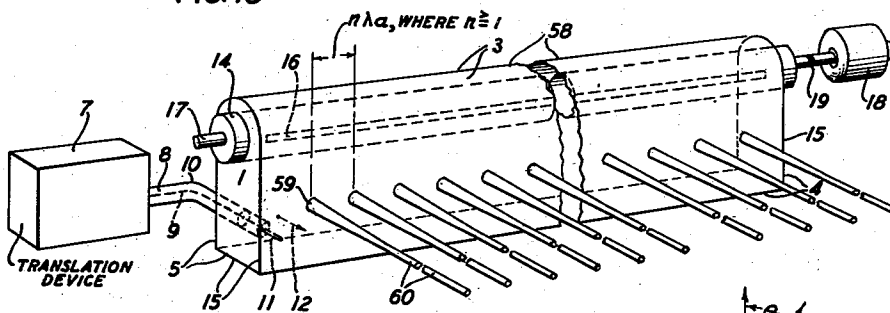
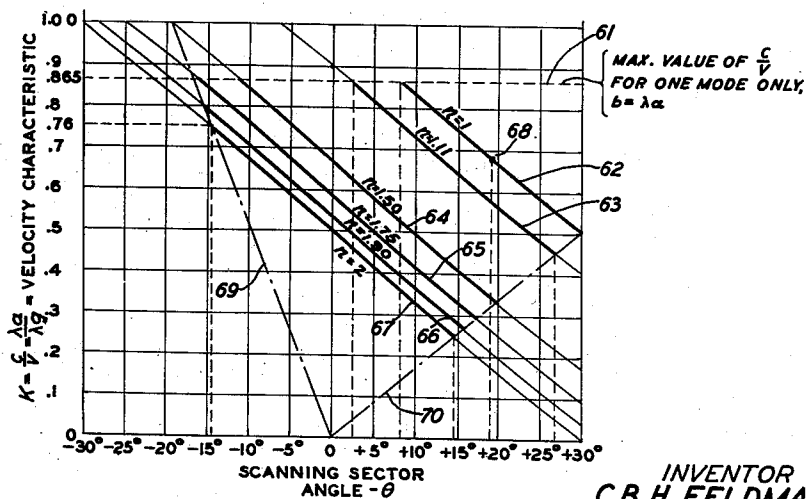


FIG. 15



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UNITED STATES PATENT OFFICE

2,594,409

DIRECTIVE ANTENNA

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Application July 27, 1943, Serial No. 496,325

11 Claims. (Cl. 250—33.63)

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This invention relates to directive antennas and particularly to centimetric directive antennas.

As is known, single unit and multiple unit directive antennas of the lobe switching and lobe sweeping types have been proposed for use in radar systems. Broadly considered, the prior art lobe sweeping antennas are of two kinds, the so-called mechanically steerable type and the so-called electrically steerable type. Ordinarily, in antenna systems of the mechanically steerable type, the entire antenna, or a part thereof, is rotated or moved and, in the case of a multiple unit system, the physical spacing between units may be varied. Also, electrically steerable antennas as heretofore proposed are of the "frequency variation" and "phase variation" types. In the frequency variation antenna system, the operating frequency is ordinarily cyclically varied; and in the phase variation antenna system, the uniform phasing of the unit antenna currents is cyclically changed, for the purpose of producing the beam sweep. While the mechanically steerable and electrically steerable antennas mentioned above are satisfactory for certain purposes, and have been used with success, it now appears desirable to obtain a lobe sweeping antenna of the electrically steerable type which possesses distinct advantages over the prior art lobe sweeping antennas. Moreover, it appears desirable to utilize, in an antenna system of the electrically steerable type designed for operation at a substantially constant frequency, means comprising a minimum number of movable parts or elements for producing the lobe sweeping action. In accordance with the present invention, and as is explained more fully herein-after, the lobe sweeping action is produced electrically by "velocity variation," that is, by varying the phase velocity of the waves delivered to or received from the antenna system.

It is one object of this invention to obtain a highly directive microwave antenna.

It is another object of this invention to vary the phase velocity characteristic of a dielectric channel.

It is another object of this invention to obtain a highly efficient lobe sweeping centimetric antenna.

It is another object of this invention to obtain a lobe sweeping antenna of compact construction and comprising a minimum number of movable parts.

It is another object of this invention to steer or change the direction of maximum action of a

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single unit antenna or a multiple unit antenna, without moving the antenna, without changing the operating frequency and without employing a plurality of phase shifters.

It is another object of this invention to produce, in an antenna system, lobe sweeping action over a scanning sector having its central direction perpendicular or broadside to the antenna or the array axis, by electrically steering the lobe without changing the operating frequency and without utilizing phase changers.

It is still another object of this invention to steer or move the directive characteristic of an electrically steerable, substantially constant frequency, antenna system comprising a wave guide having spaced antenna apertures, without employing phase shifters and without distorting the directive characteristic by second mode effects.

It is still another object of this invention to obtain, in a radar system comprising separate, closely adjacent transmitting and receiving antennas, a round trip characteristic having negligible minor lobes.

As used herein, the term "phase velocity" denoted by v is the apparent velocity of the wave along the transmission channel; and the terms "velocity ratio" and "phase velocity characteristic," both denoted by k , refer to the ratio of the phase velocity c in free space to the phase velocity v in the guide, the ratio

$$\frac{c}{v} = k$$

being equal to the ratio

$$\frac{\lambda_a}{\lambda_g}$$

where λ_a is the operating wavelength as measured in the air or ether and is designated herein the "ether wavelength," and λ_g is the operating wavelength as measured in the dielectric guide and is designated herein the "guide wavelength." For air-filled guides, V and λ_g are, respectively, greater than C and λ_a . Also, as used herein the term "transmission channel" generically includes a dielectric channel, such as a wave guide, and a line channel such as a two-wire or single-wire line.

In accordance with one embodiment of the invention, a so-called "first kind" leaky metallic wave guide antenna of the type disclosed in United States Patent 2,405,242, issued August 6, 1946, to G. C. Southworth, is equipped with an eccentric cylindraceous rotor. A translation device and a line are connected to the guide for

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utilizing H_{11} waves and the longitudinal antenna slot is located in an electric plane wall of the guide. The rotor extends longitudinally within the guide and is positioned adjacent the other electric plane wall or side. The rotor also contains a longitudinal slot and means are provided for continuously rotating the rotor. In operation, as the eccentric rotor revolves the phase velocity of the waves conveyed by the guide is cyclically varied, whereby the maximum direction of action of the slot or aperture antenna is oscillated through a desired azimuthal sector.

In accordance with a slightly different embodiment a so-called "second kind" leaky wave guide antenna of the type also disclosed in the aforementioned patent of G. C. Southworth and comprising an air-filled rectangular guide having a plurality of transverse antenna slots or circular antenna apertures in one magnetic plane wall, is equipped with a rotor of the type described above, the rotor being positioned closely adjacent to one of the electric plane walls. Each transverse or circular aperture has an individual or unit antenna directive characteristic and the several slots or apertures constitute a linear array having a space factor directive characteristic. Preferably, the distance between the adjacent apertures is such that, with the range of velocities obtainable with the selected rotor, the scanning sector may be positioned broadside. As in the embodiment first described above, the revolving rotor changes the phase velocity characteristic of the guide and, as a result, the space factor characteristic is cyclically oscillated across the major lobe of the unit characteristic. The dimensions of the rotor and of the rotor slot or aperture, are chosen so that a velocity variation range, dependent upon the spacing between the adjacent antenna apertures, is obtained which prevents the production of a second mode of lower velocity, and therefore prevents distortion of the space factor directive characteristic during its oscillation.

The invention will be more fully understood from a perusal of 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 transverse cross-sectional views of one embodiment of the invention;

Fig. 3 is a perspective view of the rotor used in the embodiment of Fig. 1; and Figs. 4 and 5 are perspective view of rotors either of which may be used in place of the rotor of Fig. 3;

Fig. 6 is a perspective view of a different embodiment of the invention; and Fig. 7 illustrates a measured receiving oscillatory directive characteristic for the embodiment of Fig. 6;

Figs. 8 and 9 are, respectively, a perspective view and a top view of a radar system in which the embodiment of Fig. 6 is utilized; and Fig. 10 illustrates the measured round trip directive characteristics for the radar system of Figs. 8 and 9;

Fig. 11 is a perspective view of another embodiment of the invention; and Fig. 12 is a directive diagram used in explaining the system of Fig. 11;

Fig. 13 is a perspective view of still another embodiment of the invention; and Figs. 14 and 15 are, respectively, a schematic diagram and a set of curves used in explaining the embodiment of Fig. 13.

Referring to Figs. 1 and 2, reference numeral

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1 denotes a rectangular air-filled metallic waveguide comprising the flat electric plane or "a" wall 2, the concave electric plane wall 3, the magnetic plane or "b" walls 4 and 5 and the enclosed air dielectric medium 6. Numeral 7 denotes a translation device, such as a transmitter, a receiver, or a radar transceiver, the device 7 being connected to a coaxial line 8 comprising inner conductor 9 and outer conductor 10. The end portion 11 of inner conductor 9 extends through wall 5 and into the dielectric medium in a direction perpendicular to walls 4 and 5, whereby transverse electric or H_{11} waves represented by arrow 12 are emitted or collected by the exposed inner conductor portion 11. If device 7 is a transmitter the conductor portion 11 constitutes an "exciter" antenna element; and if device 7 is a receiver the conductor portion 11 constitutes a "pick-up" antenna element. The front electric plane wall 2 is in a vertical plane and contains a horizontal longitudinal antenna slot 13. Reference numeral 14, Figs. 1 and 3, denotes an eccentric, hollow cylindrical or tubular rotor which extends longitudinally within guide 1 and is positioned closely adjacent the rear guide wall 3. The rotor 14 is supported near each end by the end walls 15 and contains a longitudinal slot or aperture 16. In one 10-centimeter system tested the rotor diameter was about one inch and the slot width was about $\frac{1}{2}$ of an inch. The rotor is connected through the drive shaft 17 to a motor 18, the shaft preferably but not necessarily including an insulator 19.

Assuming that device 7 is a receiver and that member 14 is not rotating, the rotor angle ψ (Fig. 2) being equal to 90 degrees, the operation of the system of Figs. 1 and 2 will now be explained. Wavelets emitted at a distant station or reflected by distant targets are collected by the slot antenna 13 and conveyed as H_{11} waves to the pick-up element 11. The collected wavelets are then conveyed by line 8 to the receiver 7. The wavelets received at any two discrete points therein as, for example, segmental antennas 20 and 21, have a phase relation, as collected, dependent upon the direction 22 of the incoming wave. If the direction 23 of maximum action for the slot antenna 13 coincides with the wave direction 22, the wavelets arrive in phase at the receiver and a maximum receiving effect is obtained. The phase velocity v in guide 1 is such that, with rotor 14 stationary, the direction 23 of maximum action of the slot antenna 13 makes an acute angle with the normal to the plane of the slot 13 as, for example, the angle $\Delta=30$ degrees, where the angle or direction $\Delta=0$ degrees is perpendicular to the plane of the slot. With motor 18 actuated the rotor 14 revolves and produces a variation in the phase velocity of guide 1, and the maximum receiving lobe including the direction 23 of maximum action, is caused to oscillate in the azimuthal plane through a given angular sector or angle $+\theta$ to $-\theta$, where $\theta=0$ is the mean or central direction of antenna action in the sector.

The theory explaining the effect produced on the phase velocity characteristic of the guide, by rotation of the eccentric rotor, is not fully understood. According to one theory, the change in phase velocity is caused by the cyclical variation of the cross-sectional area, and especially the transverse magnetic plane dimension "b" of the guide, since the frequency characteristic and the phase velocity characteristic are functions of the "b" dimension, as explained in the above-mentioned patent of G. C. Southworth. This theory,

however, is not entirely satisfactory since in certain structures the directive lobe moves more or less uniformly through the $+\theta$ to $-\theta$ sector and the change in cross-sectional or "b" dimension may not be uniform and, therefore, may not correspond to the lobe movement. According to another theory which appears plausible the rotor or velocity variator is an eccentric impedance element which functions to change or disturb cyclically the impedance of the guide and therefore the guide velocity. In a more or less analogous manner, as explained in Patent 1,562,961, R. A. Heising, November 24, 1925; Patent 2,145,024, E. Bruce, January 24, 1939 (Fig. 1), and Patent 2,236,393, A. C. Beck and H. T. Friis, March 25, 1941, the phase velocity of a conventional two-wire line may be increased by utilizing in the line a plurality of series capacitances or shunt inductances, and may be decreased by utilizing shunt capacitances or series inductances. Most likely the velocity change in the guide 1 is a result of several interrelated factors.

Referring to Figs. 4 and 5, numerals 24 and 25 designate eccentric rotors either of which may be used in the embodiment of Fig. 1 in place of rotor 14. As illustrated, the velocity variator 24 is a solid metallic semicylindrical rotor having the flat surface 26; and the velocity variator 25 is a solid cylindrical metallic rotor containing a longitudinal slot 27. Other eccentric rotors may, of course, be utilized in the system of Fig. 1.

Referring to Fig. 6, the antenna comprises, as in Fig. 1 an air-filled leaky wave guide 1 of the first kind having a longitudinal slot 13, an eccentric rotor 14 with a longitudinal aperture like aperture 16 of Fig. 1 and a motor 18 for driving the rotor. The guide 1 is connected to the translation device 7 by coaxial line 8. Numerals 28 and 29 denote a pair of parallel metallic right-triangular shield members spaced apart a distance equal approximately to the "a" dimension of guide 1. One edge 30 of member 28 is attached to the junction or linear corner formed by guide walls 2 and 4, and one edge 30 of member 29 is similarly attached to the junction of guide walls 2 and 5, in a manner such that the shields 28, 29 constitute, in a sense, extensions of the "b" walls 4, 5 of guide 1. Each member 28, 29 has an edge 31 extending perpendicularly to the wall 2 and a hypotenuse edge 32, only that one pertaining to member 28 being labeled, extending perpendicularly to the mean wave direction $\theta=0$ degrees. Since the direction $\theta=0$ degrees corresponds to the mean phase velocity characteristic of guide 1, edges 30 and 32 of each of members 28 and 29 form an acute angle which is related to the mean phase velocity in guide 1. Also, the aforementioned acute angle is equal to the acute angle Δ formed by the wave direction $\theta=0$ degrees and plane perpendicular to the plane of slot 13. In one system constructed in accordance with Fig. 6, and tested, the above-mentioned acute angle was 30 degrees. Numeral 33 denotes a side shield member included between the edges 31 of members 28 and 29 and attached to the junction of side wall 2 and one of the end walls 15 of guide 1. Thus, the arrangement or structure constitutes a "harp" antenna having a wide rectangular antenna aperture 34. Numerals 35 and numeral 36 designates side or longitudinal flanges. The flanges 35 and 36 are attached to the four edges of the rectangular antenna aperture 34 and hence constitute a horn antenna.

In operation, Fig. 6, assuming device 7 is a receiver, pulsed centimetric waves are received, after reflection from a distant target, by the wide antenna aperture 34 and guided by shield members 28, 29 and 33 to the narrow secondary antenna aperture 13 in guide 1, and are thence conveyed as H_{11} waves to device 7. As rotor 14 revolves the phase velocity characteristic of guide 1 is cyclically varied and the direction 23 of maximum radio action is oscillated across the scanning sector bounded by the directions $+\theta$ and $-\theta$. In other words, since c is a constant and v varies cyclically in accordance with the variation in the rotor slot angle ψ Fig. 2, the angle or direction θ is cyclically varied. With the rotor angle ψ equal to 0 degrees, the highest phase velocity v is obtained and with the rotor angle ψ equal to 180 degrees the lowest phase velocity v is obtained.

While the vertical plane of the slot 13 is angularly related to the azimuthal or horizontal scanning plane containing the direction θ the rectangular antenna aperture 34 is included in the vertical wave front plane which is perpendicular to the scanning plane. Thus, in a sense, the shield members 28, 29 and 33 project the slot antenna aperture 13 into the vertical wave front plane for the direction $\theta=0$ degrees. Stated differently, the $+\theta$ and $-\theta$ scanning sector, or more accurately the mean direction $\theta=0$ degrees, is, relative to aperture 34, in the so-called broadside position. On the other hand, in the embodiment of Fig. 1, the azimuthal scanning sector is in the oblique position, that is, at an acute angle to the antenna slot 13. In addition, the shields 28 and 29 function, in effect, to change or transform the narrow antenna aperture 13 into a wide antenna aperture 34, whereby the lobe width in the plane perpendicular to the scanning plane is decreased and the gain of the system is increased. As pointed out below, in the radar system of Figs. 8 and 9, the shields also prevent interaction between the separate transmitting and receiving antennas. The flares 36 function as a horn and further decrease the lobe width in the plane perpendicular to the scanning plane.

The curves of Fig. 7 were obtained during a receiving test of the system of Fig. 6. In Fig. 7 the lobe 37 shown in full line and having its principal axis or direction 23 aligned with the $\theta=-7$ degree direction, approximately, corresponds to the $\psi=0$ position (Fig. 2) of rotor 14; and the lobe 37 shown in dash line and aligned with the $\theta=+3$ degree direction, approximately, corresponds to the $\psi=180$ -degree rotor position. During the test the velocity variator 14 functioned to oscillate direction 23 of the maximum lobe 37 through the 10-degree sector bounded by the -7 degree and $+3$ degree directions. In this connection it is important to note that lobe 37 is not switched from the full line to the dash line position but moves, back and forth, across the sector, as indicated on the drawing by the two peaks of lobe 37 included between the full line and dash line lobe positions.

Figs. 8 and 9 illustrate a radar system comprising a transmitting harp antenna 38 connected by line 8 to the transmitter 39 and a receiving harp antenna 40 connected by line 8 to the receiver 41. The harp receiving antenna 40 is the same as that illustrated by Fig. 6. The harp antennas 38 and 40 differ primarily in that the transmitting antenna 38 is not equipped with a velocity variation rotor and each right-angle

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shield member 28, 29 has two 45-degree acute angles, whereas the receiving antenna 40 is equipped with a velocity variator 14 and each of the right-angle shield members 28 and 29 has a 30-degree angle and a 60-degree angle. The guide 1 of the 45-degree antenna 38 has a wider "b" or magnetic plane dimension than guide 1 of the 30-60 degree antenna 40, since the angle between the slot 13 of antenna 38 and its direction of maximum action is 45 degrees whereas the angle between slot 13 of antenna 40 and its direction of maximum action is 60 degrees. Also, the rear guide wall of antenna 38 is flat, whereas the corresponding guide wall of antenna 40 is preferably made concave, as described previously, to accommodate the rotor 14. The structures are superimposed so that their projected apertures 34 are included in the same vertical plane and their corresponding end flanges 35 are aligned. It will be observed that the transmission lines 8 are connected to the guides 1 near uncorrespondent ends of the guides so that the energies in the two guides 1 flow in opposing or diverging directions 42. Hence, considering the longitudinal axes of the two rectangular apertures 34 the directions of energy flow are exactly opposite, that is, the two antenna apertures have a reversed feed, as shown by arrows 43.

In operation, Figs. 8 and 9, pulsed centimetric waves are supplied over line 8 by transmitter 39 to antenna 38 and maximum radiation occurs in a direction 44 corresponding to $\theta=0$ degrees and perpendicular to the rectangular aperture 34. The stationary maximum transmitting lobe is sufficiently broad to blanket or illuminate with radio energy the desired azimuthal sector bounded by the angular directions $+\theta$ and $-\theta$. Hence, pulses impinge upon all reflective objects disposed in the sector and are returned as echo waves to the receiving antenna 40. The motor-driven rotor 14 of the harp receiving antenna 40 causes the maximum lobe of the receiving antenna to oscillate and scan the $+\theta$ and $-\theta$ degree sector. More specifically, the maximum lobe, including the direction 23 of maximum action, of the receiving antenna 40, moves across the sector and the echo pulses are successively received, the receiver being preferably adjusted so that the directional indication obtained is related to the direction 23 of maximum antenna action rather than to a direction of minor antenna action. The transmitting antenna may, if desired, be equipped with a rotor for the purpose of oscillating the maximum transmitting lobe.

The direction 44, Fig. 9, represents the principal axis of the primary maximum lobe of the transmitting antenna 38 and the direction 23 represents the principal axis of the primary maximum lobe of the receiving antenna 40. These primary lobes are established by the so-called "go" waves in the guides 1 of antennas 38 and 40. In each of the guides 1 the "return" waves, reflected by the end wall 15 remote from the coaxial line connection, establish a pronounced minor lobe at an angle to the axis of the slot antenna 13 equal to the angle between the maximum lobe and the slot axis. In addition, in the case of each slot 13, one or more minor lobes having directions included between the maximum lobe and the slot axis are established by a component having a lower velocity mode. In Fig. 9, reference numerals 45 and 46 denote the principal axes of the pronounced un-

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desired "reflection" lobes, and numerals 47 and 48 denote the principal axes of the undesired "lower velocity" lobes, respectively, for antennas 38 and 40. The functional labels T, L and R refer to what has just been described as "principal," "lower velocity" and "reflection," respectively. By utilizing a reversed feed for the two superimposed guides 1 of antennas 38 and 40, which antennas have their maximum lobe axes 23 and 44 superimposed or coincident, the lower velocity lobes 47 and 48 are displaced and in fact are established on opposite sides of axes 23, 44, so that they do not combine to form a pronounced round trip lower velocity lobe. As is known, the round trip directive characteristic for the system of Figs. 8 and 9 is the product of the receiving and transmitting characteristics, as expressed in terms of the square root of the power. Considering the reflection lobes 45 and 46, these lobes would not align if the reversed feed were not used, since the antennas 38 and 40 have dissimilar angles. The reversed feed, however, insures the establishment of these lobes on opposite sides of directions 23, 44. Hence a highly desirable round trip characteristic having no pronounced minor lobes is obtained. The reversed feed necessitates, in part, orienting the two slots 13 at an angle, and the shields 28 and 29 function to prevent interaction between the angularly related slots. If antennas 38 and 40 had similar angles, and if the reversed feed were not used, it would be practical to include the slots 13 in the same vertical plane. In this case the shields 28 and 29 would not be necessary, and only horn flares, such as flares 36, would be required to prevent interaction.

Referring to Fig. 10 which illustrates the round trip directive characteristic for the radar system of Figs. 8 and 9, reference numerals 49, 50 and 51 denote the positions of the round trip lobe corresponding, respectively, to the rotor positions, Fig. 2, $\psi=0$ degrees, $\psi=90$ degrees and $\psi=180$ degrees. The lobe position for the $\psi=270$ degrees is substantially the same as that obtained for the rotor position $\psi=90$ degrees. For the positions $\psi=0$ degrees, $\psi=90$ degrees and $\psi=180$ degrees the lobe is aligned, respectively with the directions $\theta=-4$ degrees, $\theta=0$ degrees and $\theta=+4$ degrees. Hence, during the test, the lobe oscillated between the $+4$ degree and -4 degree directions. It will be noted that the round trip characteristic does not include pronounced minor lobes.

Referring to Fig. 11, reference numeral 52 denotes a leaky wave guide of the second kind having electric plane or a walls 2 and 3, magnetic plane or b walls 4 and 5 and end walls 15. The front wall 4 contains a plurality of transverse antenna slots 53 each extending perpendicularly to the electric walls 2 and 3. The areas of slots 53 are preferably tapered or graduated, as illustrated, for the purpose of equalizing the energies emitted or collected by the separate slots. The spacing between slots is $n\lambda_a$ where λ_a is the ether wavelength and n is equal to or less than 0.5. The guide 52 is equipped with an eccentric longitudinal rotor 14 which contains a longitudinal slot 16 and is connected by a shaft 17 to the motor 18. As in Fig. 1, the leaky guide 52 is connected to translation device 7 by coaxial line 8 comprising inner conductor 9 and outer conductor 10. The exciter or pick-up 11 extends into the guide in a direction such that H_{11} waves radiated or received have a polarization 12 perpendicular to the guide wall 4. It will be noted that

in the guide antennas of Figs. 1, 6, 8 and 9 the wave polarization is perpendicular to the scanning plane whereas in the guide antenna of Fig. 11 (and Fig. 13) the wave polarization is parallel to the scanning plane.

In operation, referring to Figs. 11 and 12 and assuming device 7 is a pulse transceiver, pulses are supplied by device 7 over line 8 to guide 52, and, for each pulse, distinct wavelets are simultaneously emitted by the rectangular apertures 53. The pulses are received after reflection at a distant target and conveyed over line 8 to transceiver 7. The maximum directive lobe of each aperture antenna 53 is not sharp and in Fig. 12 is represented by the curve 54. During the transmission and subsequent reception of the pulses, the motor driven rotor 14 causes the maximum space factor lobe 55, Fig. 12, of the linear array comprising apertures 53 to move back and forth across the effective aperture lobe and therefore causes the resultant or product lobe 56 to oscillate and scan the desired angular sector 57. The rate of sweep or scan is determined by the speed of the rotor and the rotor speed and the pulsing rate are preferably such that in transmission a large number of pulses are emitted during each oscillation of the maximum resultant lobe 56. The angle

$$\cos^{-1} \frac{c}{v}$$

between the array axis and the direction of maximum action is other than 90 degrees, that is, the scanning sector is not positioned broadside. Assuming, as shown in Fig. 11, that the slots 53 are spaced less than a half a wavelength, the direction of maximum action is the same as in the case of leaky wave guides of the first kind and no significant secondary maxima should occur. It may be noted that if the slot spacing in structure of Fig. 11 were greater than one wavelength, as in the system of Fig. 13 described below, the space factor characteristic would include two or more maximum lobes; and if it were greater than one-half wavelength and less than one wavelength the characteristic may include more than one maximum lobe.

Referring to Fig. 13, reference numeral 58 denotes a leaky wave guide of the second kind having in its front electric plane wall 4 the longitudinally spaced circular apertures 59, and numerals 60 designate end-on polystyrene antenna elements each of which projects into, and is supported in, one of the apertures 59. The polystyrene elements or polyrods 60 are of the type disclosed in my copending application Serial No. 464,479, filed November 4, 1942, Patent No. 2,419,205 issued April 2, 1947, and the copending application of G. E. Mueller, Serial No. 469,284, filed December 17, 1942, Patent No. 2,425,336 issued August 12, 1947. As disclosed in the Mueller application the polyrods 60 are tapered for the purpose of securing a directive characteristic having a single maximum lobe of selected width and negligible minor lobes. As discussed below the spacing between adjacent polyrods 60 is greater than one wavelength and preferably in the order of one and one-half to two wavelengths, and the range of the phase velocity variation is selected in accordance with the polyrod spacing, or vice versa.

Referring to Figs. 14 and 15 the manner of determining the proper range of phase velocity variation for a given value of n , greater than 1.0, will now be explained. First of all, the velocity

ratio or phase velocity characteristic k must be such, as explained below, that a phase velocity corresponding to a second mode of the wave is not established in the guide, otherwise the space factor directive characteristic, corresponding to the desired operating frequency, of the linear array comprising polyrods 60 would be greatly distorted. As discussed in Patent 2,129,669, A. E. Bowen, September 13, 1938, the wavelength in a rectangular air-filled guide conveying H_{11} waves is controlled by the dimension b and the limiting condition for preventing the second mode is

$$b = \lambda_a \quad (1)$$

where λ_a is the ether wavelength.

The equation, as given in the Bowen patent, expressing the relation for λ_a , b and λ_g , is

$$\lambda_a = \frac{\lambda_g}{\sqrt{1 - \left(\frac{\lambda_g}{2b}\right)^2}} \quad (2)$$

where λ_g is the guide wavelength, or

$$\frac{\lambda_a}{\lambda_g} = \sqrt{1 - \left(\frac{\lambda_g}{2b}\right)^2} = k \quad (3)$$

letting

$$\frac{\lambda_a}{\lambda_g} = \frac{c}{v} \quad (4)$$

and substituting λ_a for b , we have

$$\frac{c}{v} = \sqrt{1 - \left(\frac{1}{2}\right)^2} = 0.865 = k \quad (5)$$

Hence, as a first limitation, the phase velocity ratio or characteristic

$$\frac{c}{v}$$

must be equal to or smaller than 0.865, as is indicated by the horizontal broken line 61 in Fig. 15.

Referring to Fig. 13, the phase shift between adjacent apertures or polyrods is

$$\frac{n\lambda_a}{\lambda_g} \text{ 360 degrees} \quad (6)$$

In order to get maximum radio action at any angle θ , this phase shift must differ from 360 degrees by the quantity

$$\frac{n\lambda_a \sin \theta}{\lambda_g} \text{ 360 degrees} \quad (7)$$

That is,

$$360 \pm (n \sin \theta) 360 = \frac{n\lambda_a}{\lambda_g} 360 \quad (8)$$

Since

$$\frac{c}{v} = \frac{\lambda_a}{\lambda_g} \quad (9)$$

we have by substituting

$$1 \pm n \sin \theta = \frac{c}{v} \quad (10)$$

or

$$\frac{c}{v} = \frac{1}{n} \pm \sin \theta = k \quad (11)$$

From Equation 11, for each direction θ in a desired azimuthal sector and a given value of n , the velocity characteristic k may be determined. Referring to Fig. 15, the curves $n=1$, $n=1.11$, $n=1.50$, $n=1.75$, $n=1.90$ and $n=2$, designated respectively by reference numerals 62, 63, 64, 65, 66 and 67, were determined in this manner. It will be observed that, for a spacing of one wavelength ($n=1$) and a range of 0.5 to 0.865 for the

velocity ratio k ; a scanning sector extending from $+8$ degrees to $+30$ degrees, as illustrated by line 62, is obtained without second mode effects; the sector being centered approximately on the $+19$ degree direction denoted by reference numeral 68. With $n=1$, a second mode distortion is obtained for directions less than $\theta=8$ degrees, since for these directions the value of k exceeds 0.865. With $n=2$, a 29 degree ($\pm\theta=14.5$ degrees) scanning sector extending broadside and having its mean direction perpendicular to the plane of the polyrods 60 may be secured by dimensioning the velocity variator 14 so that k varies over the range 0.23 approximately to 0.76 approximately. In accordance with the invention, the dimensions of the variator 14 and especially of the variator slot 16 are selected to give the proper velocity variation for a given constant operating frequency, a given value of n and a given desired angular scanning sector $\pm\theta$, preferably but not necessarily, centered on the $\theta=0$ direction. In this connection, it may be noted that the proper width of slot 16 in rotor 14, Fig. 3, or the proper width and proper depth of slot 27 in rotor 25 of Fig. 5, for securing a desired variation in k , may be easily determined experimentally, inasmuch as rotor 14 without the slot 16 or rotor 27 without the slot 27 produces no velocity variation.

The operation of the system of Fig. 13 is believed to be apparent in view of the description given above relative to Fig. 11. Briefly, pulses are supplied by device 7 over line 8 to guide 58 and, for each pulse, distinct wavelets are simultaneously emitted by the polyrods 60. Assuming $n=2$, during the transmission and subsequent reception of the pulses, the motor driven rotor 14 causes the primary space factor lobe to oscillate across the 29 degree sector, Fig. 15, and across the major lobe of each polyrod 60. As shown by the dash-dot lines 69 and 70, Fig. 15, which traverse the lines 65, 66 and 67, with the primary maximum lobe at one extremity of the scanning sector, a secondary maximum lobe occurs at the other extremity. Thus for $n=2$, assuming the primary lobe is moving from the $\theta=0$ direction to the -15 degree direction, a secondary maximum lobe appears at the $+15$ degree as the primary lobe reaches the -15 degree direction. As disclosed in my copending application, mentioned above, the minor lobes of the directive characteristic of each polyrod 60 should have negligible intensities; and the shape of the polyrod major lobe should be such that, during the scanning, only one maximum space factor or array lobe intercepts at any given instant the polyrod major lobe whereby unambiguous scanning is secured.

Although the invention has been explained in connection with certain embodiments, it should be understood that it is not to be limited to the embodiments described, inasmuch as other apparatus may be satisfactorily employed in practicing the invention.

What is claimed is:

1. In combination, a metallic rectangular wave guide, means for supplying to or receiving from said guide transverse electric centimetric waves polarized perpendicularly to one pair of wave guide walls, a plurality of antenna apertures spaced along a longitudinal dimension of one of said walls and constituting a linear antenna array, and means extending longitudinally within said guide for changing the distributed impedance of said guide whereby the phase velocity of the waves conveyed in said guide is varied and

the space factor directive characteristic of said array is moved relative to said longitudinal dimension.

2. In combination, a wave guide having at least one metallic wall, means for supplying to or receiving from said guide centimetric waves, polarized perpendicularly to said wall, a linear antenna array comprising a plurality of parallel rectangular slots or apertures spaced along a longitudinal dimension of said wall, and means extending longitudinally within said guide for varying the phase velocity of the waves in said guide.

3. In combination, a radio translation device, a wave guide connected thereto and having in one wall a plurality of unit antennas spaced longitudinally, means for impressing on said wave guide a wave of a substantially constant frequency, and independent means for varying the phase velocity characteristic of said guide over a range related to said spacing.

4. In combination, a radio translation device, a wave guide connected thereto and having in one wall a plurality of unit antennas spaced longitudinally, means for impressing on said wave guide a wave of a substantially constant frequency, and independent means for varying the phase velocity characteristic over a range related to said spacing and including a mean value corresponding to a wave direction perpendicular to said wall.

5. In combination, a radio translation device, a rectangular wave guide connected thereto and having in one wall a plurality of antenna apertures spaced longitudinally, means for impressing on said wave guide a wave of a substantially constant frequency, and independent means for varying the phase velocity characteristic over a range related to said spacing, one value in said range corresponding to a wave direction perpendicular to said wall and each value in said range being smaller than 0.865.

6. In combination, a radio transceiver, a wave guide connected thereto and having in one wall a plurality of antenna apertures spaced along a longitudinal wall dimension, the spacing between apertures being greater than one-half the operating ether wavelength, means for impressing on said wave guide a wave of a substantially constant frequency, and independent means for varying the guide phase velocity over a range related to said spacing and including a value corresponding to broadside ratio action.

7. In combination, a wave guide having at least one metallic wall, means for supplying to or receiving from said guide centimetric waves, a linear antenna array comprising a plurality of graded circular apertures spaced along a longitudinal dimension of said guide wall, and having individual directive lobes, and means extending longitudinally within said guide for cyclically varying the phase velocity of the waves in said guide, whereby the maximum lobe of the space factor directive characteristic is cyclically moved across the individual lobes.

8. In combination, a rectangular wave guide having a longitudinal slot in a first side wall for directionally receiving centimetric waves, a receiver connected thereto for utilizing a transverse electric wave component of said waves polarized perpendicularly to said wall, means within said guide for cyclically varying the phase velocity of said components, and a pair of triangular metallic shield members extending from the linear

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junctions of said first wall and the adjacent guide walls in directions parallel to said adjacent walls, one edge or border of each shield member being perpendicular to said first wall and another edge or border being perpendicular to the mean wave direction.

9. In combination, a transmitting antenna comprising a first rectangular wave guide having a longitudinal slot in one wall for directionally radiating centimetric waves and a first pair of parallel triangular shield members attached to said wall, a receiving antenna comprising a second rectangular wave guide having in one wall a longitudinal slot for directionally receiving said wave after reflection from a distant surface and a second pair of parallel triangular metallic shield members attached to the last-mentioned wall, the longest edges or sides of said four shield members being included in the same plane, a transmitter connected to the first guide and a receiver connected to the second guide, means included in the second guide for cyclically varying the phase velocity of the received components.

10. In combination, a metallic rectangular air-filled wave guide, a centimetric transceiver connected therewith, one of the guide walls having a longitudinal antenna slot, an eccentric member comprising a cylindrical air-filled metallic rotor having a longitudinal slot, extending lon-

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gitudinally within said guide and facing the first-mentioned guide wall, and means for continuously rotating said member.

11. In combination, a metallic rectangular air-filled wave guide, a centimetric transceiver connected therewith, one of the guide walls having a longitudinal antenna slot, an eccentric member comprising a cylindrical solid metallic rotor having a longitudinal slot, extending longitudinally within said guide and facing the first-mentioned guide wall, and means for continuously rotating said member.

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