

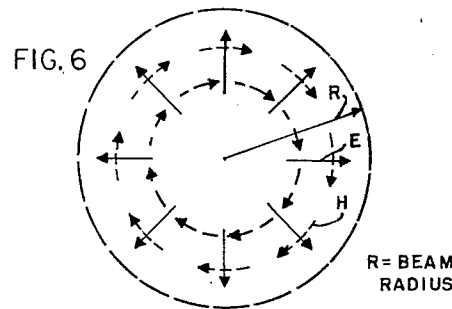
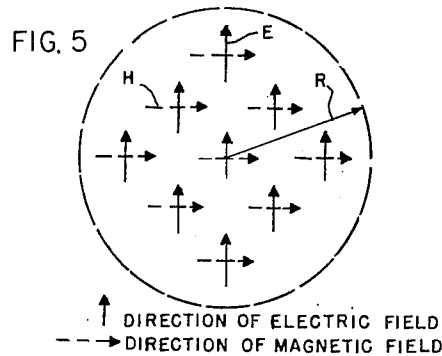
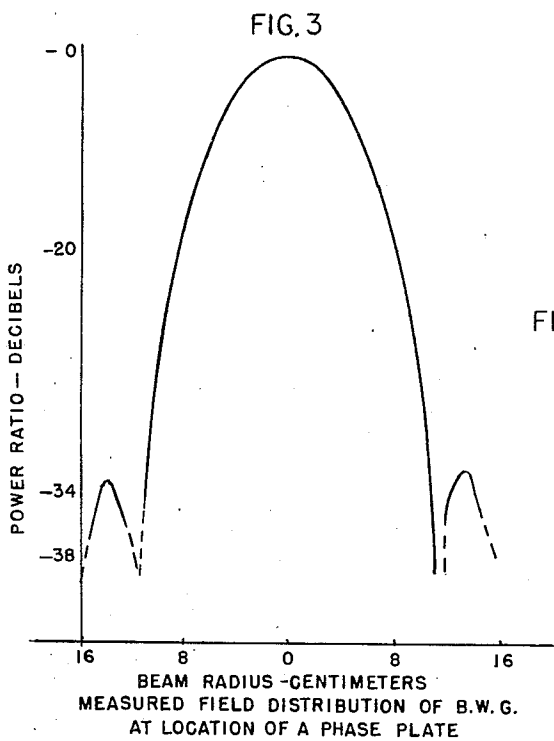
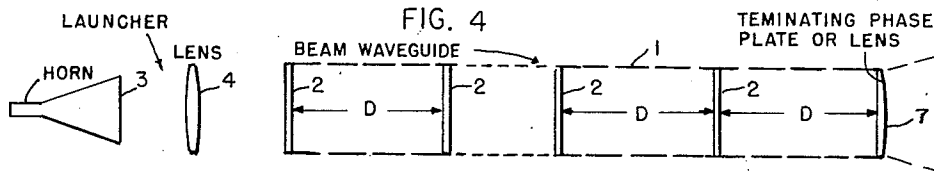
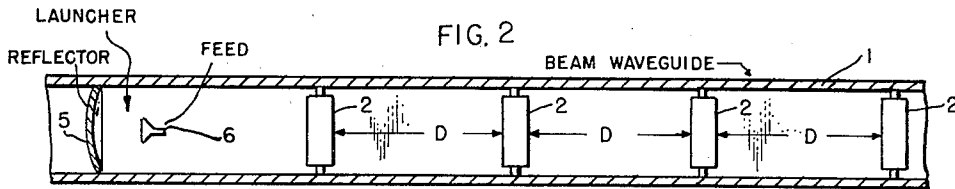
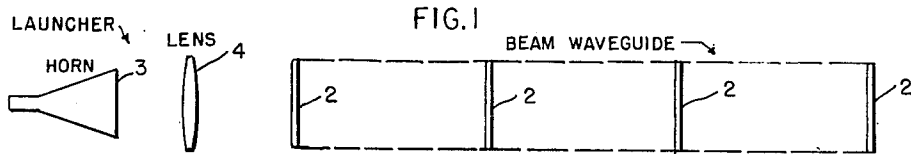
Aug. 1, 1961

G. J. E. GOUBAU
BEAM-WAVEGUIDE ANTENNA

2,994,873

Filed Aug. 5, 1959

3 Sheets-Sheet 1



INVENTOR,
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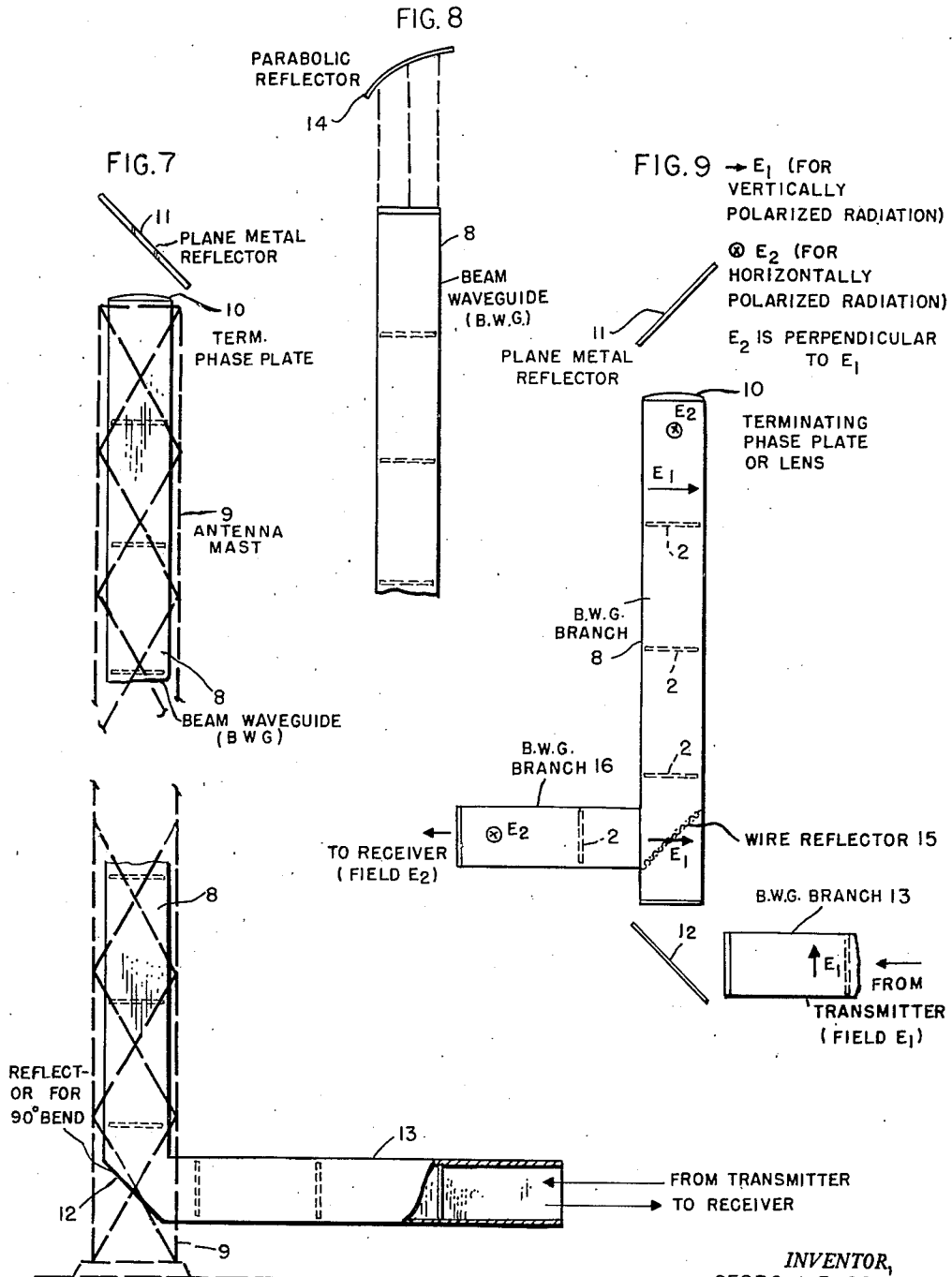
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FIG. 10

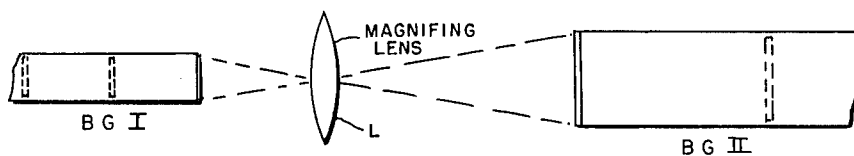


FIG. 11

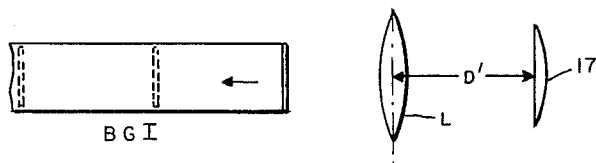
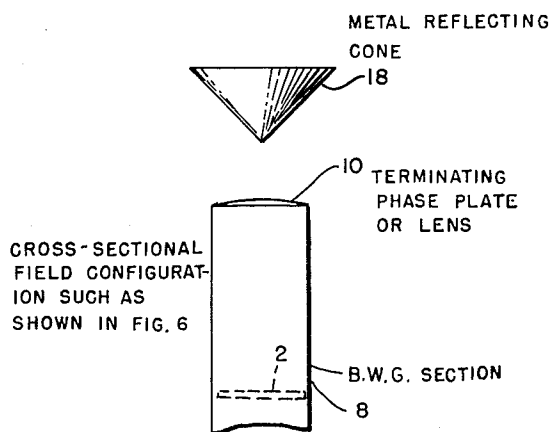


FIG. 12



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2,994,873

BEAM-WAVEGUIDE ANTENNA

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Filed Aug. 5, 1959, Ser. No. 831,916

10 Claims. (Cl. 343-753)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment of any royalty thereon.

The invention relates to directive antennas for the radiation and reception of electromagnetic wave energy, and particularly to such antennas of the waveguide type especially adapted for radio communication or radar systems operating in the centimeter and millimeter wavelength regions.

The antennas of the invention were specifically designed for connection to transmission lines of the so-called "beam-waveguide" type, such as are disclosed and claimed in applicant's co-pending patent application, Serial No. 775,402, filed November 21, 1958, for which use they are particularly adapted, but also may be used advantageously for connection to other types of transmission lines at the radio system terminals.

The "beam-waveguide" type of transmission line, to be referred to hereinafter as a B.W.G., as disclosed in the aforementioned application, is a new type of waveguide adapted to propagate a beam of electromagnetic wave energy confined to a substantially cylindrical space without actual boundary. It comprises a plurality of appropriately designed phase-correcting plates, such as dielectric lenses of predetermined focal length, inserted into the path of a propagated electromagnetic wave beam at respective spaced intervals which are long in comparison to the radius of the beam and very long compared to its wavelength. Each phase plate or lens intercepts the beam and reshapes it by resetting the phase distribution in the beam cross-section to the original distribution, that is, it compensates for the diffractive expansion occurring in the beam after it passes the preceding phase plate. The phase correction required by the phase plates is given by the formula

$$\varphi = \frac{Kr^2}{D} \quad (1)$$

where φ is the phase advance at a distance r from the axis, D is the distance between successive phase plates and K is a constant. The phase plates may be designed as lenses each having a focal length of $D/2$. If ray-optical considerations were to apply, each phase plate or lens would image the preceding phase plate into the succeeding phase plate. However, since the operational frequencies are too low for ray-optical imaging, the distribution of the beam energy after passing a phase plate is determined by diffraction. A characteristic feature of the beam-waveguide is that the diffraction pattern obtained has very small, or low level, side lobes. These side lobes by-pass the phase plate and are eliminated from the propagated beam. The net effect is that the beam energy remains substantially confined within a cylindrical space the diameter of which is determined by the diameter of the phase plates.

The B.W.G., as above described, obviously can be used as a transmission line to feed a conventional elevated antenna. In this case, the energy of the wave beam must first be converted into a conventional waveguide mode which is fed to the antenna which converts it into radiation. These two conversions can be replaced by a single one. There are several possible ways for accomplishing such conversion depending on the desired radiation

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characteristic. The combining of a B.W.G. with a conventional antenna, such as one of the parabolic reflector type, would require the use of an additional transducer or wave launcher for converting the propagated wave beam energy into a conventional waveguide mode which would introduce additional loss into the system. Also, the antenna feed itself would cause inherent loss in the antenna system due to imperfect illumination of the parabolic reflector.

One object of the invention is to provide an improved antenna for operation with a beam-waveguide line, as above described, in a radio system, which will operate efficiently, that is, without introducing appreciable loss into the system, to convert the substantially cylindrical wave beam propagated over that line into a conical beam for radiation into space.

More specific objects are to provide antenna systems for producing directional radiation and reception of high frequency electromagnetic wave energy which are efficient in operation; have no rotary joints in the case of scanning antennas; and are of simple design and economical to manufacture.

These objects are attained in accordance with the invention by an antenna system comprising the combination of a section of beam-waveguide (B.W.G.), which may be an extension of an existing B.W.G. line, with one or more other simple elements to achieve radiation into space in a very efficient manner. In its simplest form, the antenna would comprise a section of B.W.G. (with only one launcher) with one terminating phase plate removed and replaced with a lens of suitable design to convert the supplied cylindrically-shaped signal wave beam into conical form for radiation into space.

In a second embodiment of the invention representing an elevated antenna adapted for radiation of an electromagnetic wave beam in a horizontal direction or at any desired angle with respect to the horizontal direction, a section of a B.W.G. is mounted vertically within a mast member, and the conversion of the substantially cylindrical electromagnetic wave beam propagated over this section for radiation into space is accomplished in two simple steps; namely, (1) a phase correction provided by the replacement of the upper (last) phase plate or lens of the B.W.G. by another lens having twice its focal length, and (2) a beam deflection, provided by a plane metal reflector mounted above the latter lens and disposed at a suitable angle (say, 45° in the case of horizontal radiation) with respect to the longitudinal axis of a vertically-disposed portion of the B.W.G. section, to reflect the beam energy passed by the latter lens into space in the desired direction.

A third embodiment differs essentially from the second embodiment as above described in the use of a reflecting metal cone of appropriate angle in place of the plane metal reflector, following the terminating lens, to provide an omnidirectional antenna.

A feature of all embodiments of the invention is that, because of the incorporation of the B.W.G. section therein, the side lobes of the radiated signal beam are very low compared to the main lobe thereof.

The above-mentioned and other features and objects of the invention will be better understood from the following detailed description thereof when it is read in conjunction with the several figures of the accompanying drawings in which:

FIGS. 1 and 2 respectively show diagrammatically alternative means applied to a section of beam-waveguide line (B.W.G.), which may be used to launch in, or receive from, that line section the beam of electromagnetic signal energy propagated thereover;

FIG. 3 is a curve showing the measured cross-sectional field distribution of the beam of electromagnetic wave

energy in a section of B.W.G. at the location of a phase plate therein, obtained from an experimental set-up in accordance with FIG. 1;

FIG. 4 shows diagrammatically the simplest arrangement of a beam-waveguide antenna embodying the invention;

FIGS. 5 and 6 respectively show the cross-sectional field configurations for wave beams of different propagated modes in a B.W.G. required to produce maximum radiation in certain directions;

FIG. 7 shows an elevation view of a second embodiment of a beam-waveguide antenna in accordance with the invention;

FIGS. 8 to 11 respectively show diagrammatically different modifications which may be made in the basic beam-waveguide embodiments of FIGS. 4 and 7, in accordance with the invention; and

FIG. 12 shows diagrammatically a portion of an omnidirectional beam-waveguide antenna system embodying the invention.

FIGS. 1 and 2, identical with FIGS. 4A and 4B of the aforementioned application, show diagrammatical or sectional representations, respectively, of a section of beam-waveguide (B.W.G.) adapted for propagating a beam of high frequency electromagnetic wave energy confined to a substantially cylindrical space, with associated different structures for launching the wave beam in, or receiving it from this line section. In FIG. 1, the beam-waveguide has no physical boundary around the beam; in FIG. 2 the beam is inclosed in a protective tube 1 of a material which is preferably dissipative, such as concrete. As shown in these figures, the B.W.G. comprises a plurality of properly designed phase-correcting plates 2 in the path of a propagated beam at equally spaced points along its length, each two successive phase plates being separated by the same distance D which is much larger than the diameter of the beam and very large compared to its wavelength. The plates 2, as described in the aforementioned application, may be lenses made from a dielectric material, such as polystyrene, each having a focal length of $D/2$ and freed from substantial surface reflection by any suitable means several of which are described in that application.

The launching and receiving of the beam of electromagnetic wave energy propagated by the B.W.G. may be done by means of an electromagnetic horn 3 combined with one or more lenses 4 of suitable curvature for obtaining an appropriate cross-sectional amplitude and phase distribution of the beam (FIG. 1), or by means of a parabolic reflector 5 with a conventional feed 6 placed off the focal point of the parabola (FIG. 2). In general, any beam-forming structure may be used in place of those illustrated in these figures, if it can be adapted for forming an electromagnetic wave beam of substantially cylindrical form.

The curve of FIG. 3 shows the measured cross-sectional field distribution (power ratio in decibels plotted against radius in centimeters) of the beam of a B.W.G. at the location of a phase plate, using a field configuration such as shown in FIG. 5, obtained with an experimental set-up in accordance with FIG. 1, for $R^2/\lambda D = 0.75$, where R is the beam radius, D is the distance between successive phase plates and λ is the wavelength. As indicated in FIG. 3, the preliminary measurements showed that the side lobes of the produced electromagnetic wave beam are more than 30 decibels below the level of the main lobe thereof. A larger value of " $R^2/\lambda D$ " would yield even smaller side lobes. This desirable feature of the B.W.G. is utilized in the beam-waveguide antennas of the invention to be described, to obtain a corresponding low side lobe characteristic for the conical beam radiated by the antenna. If $f(r)$ is the radial field distribution of the B.W.G. beam at the location of a phase plate, then the angular distribution of the conical beam is $f(D\theta)$, where D is the spacing of the

phase plates in the B.W.G. and θ is the angle of the direction of observation with respect to the axis of the radiated beam.

FIG. 4 shows the simplest arrangement of the beam-waveguide antenna in accordance with the invention. It differs from the B.W.G. merely in the replacement of one of the usual B.W.G. terminations (that is, one launcher of FIG. 1 or FIG. 2) by an appropriately designed terminating phase plate or lens 7 to achieve the transformation of the cylindrical beam of the B.W.G. into a conical beam. This terminating plate 7 is designed to effect half the phase shift of the other phase plates 2 of the B.W.G. at corresponding cross-sectional points in the beam. The distance of the terminating plate 7 from the nearest adjacent phase plate 2 is equal to the mutual spacing D between the other successive phase plates 2 in the B.W.G. If the terminating phase plate 7 is designed as a lens, the focal length of this lens must also be equal to D. In order to obtain maximum radiation in the forward direction with the antenna of FIG. 4, a wave beam with the field configuration shown in FIG. 5 (corresponding to FIG. 12 of the aforementioned application) must be used. The 3-decibel beam width (B.W.) of the radiation characteristic of the antenna of FIG. 4 is given by the approximate formula:

$$(B.W.) \approx 0.86 \frac{R}{D} \frac{360}{2\pi} \text{ degrees} \quad (2)$$

where R is the effective radius of each of the phase plates.

If the beam produced by the beam-waveguide antenna of FIG. 4 has the field configuration of FIG. 6 (corresponding to FIG. 14 of the aforementioned application), the radiation along the longitudinal axis is zero, and the maximum radiation will occur along the line having a certain angle with respect to this axis.

The conical beam radiated by a beam-waveguide antenna can be reflected in any direction by means of a plane metal reflector. FIG. 7 shows one embodiment of an elevated beam-waveguide antenna in accordance with the invention in which the end portion 8 of a B.W.G. is mounted vertically within an antenna mast member 9, and the uppermost phase plate or lens 10 of the B.W.G., corresponding to the terminating phase plate 7 of the B.W.G. section in the beam-waveguide antenna of FIG. 4, is designed to have twice its focal length, and the conical beam produced by 10 is reflected by the properly angularly-disposed plane metal reflector 11 in a desired horizontal direction. A second reflector plate 12 may be utilized, as shown in FIG. 7, at an intermediate point in the B.W.G. section to form a 90° angular band therein to provide a corresponding reflection of the substantially cylindrical electromagnetic wave beam propagated thereover from the radio transmitter to the terminating phase plate or lens 10, or from the terminating phase plate 10 to the radio receiver, where the radio transmitter and the radio receiver are connected to the horizontally-disposed portion 13 of the B.W.G. section as shown in the figure.

The terminating phase plate or lens 10 can be omitted in the beam-waveguide antenna of FIG. 7 if an appropriately curved reflector for performing the combined functions of that lens and the plane reflector is substituted for the plane reflector 11, as shown at 14 in FIG. 8.

Cross-polarization may be applied to a beam-waveguide antenna of the basic type shown in FIG. 7 to enable the simultaneous use of this antenna to provide transmission and reception of ultra-high frequency electromagnetic wave signal beams at the same or different frequencies, as shown in FIG. 9. Referring to that figure, the signal (radio) transmitter feeds outgoing signals in the form of an electromagnetic wave beam having a vertical electric field polarization, indicated in the figure by the vector designated E_v , into the horizontally-disposed branch 13 of the B.W.G. section. The beam after passing over that

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branch is reflected by reflector 12 into the vertically-disposed branch 8 of the B.W.G. section, and will pass to the upper (terminating) phase plate or lens 10 with the energy confined to a substantially cylindrical space due to the effects produced by the preceding phase plates 2 in the B.W.G. section. The terminating phase plate 10 will convert the outgoing signal beam to the conical form and will deliver it in that form to the adjacent angularly-disposed plane reflector 11 which will reflect the conical signal beam into space in the desired horizontal direction.

The incoming signals of the same frequency as the outgoing signals, or of a different frequency, but having a horizontal electric field polarization, indicated on the figure by the vector designated E_2 , intercepted by the reflector plate 11 will be reflected into the vertically-disposed branch 8 of the B.W.G. section through the terminating phase plate 10 of that section. The reflected energy will be propagated over the branch 8 confined to a substantially cylindrical space and will be intercepted by the wire reflector 15 extending across the interior of that branch at an intermediate point at an angle of 45° with respect to the longitudinal axis of the branch 8. The wire reflector 15 may consist of a grid of parallel wires spaced from each other by a distance less than a half-wavelength ($\lambda/2$) of the signal frequency, which wires extend in parallel with the electric field E_2 and therefore operate to reflect only the incoming signal beam having the horizontally polarized electric field E_2 into a third horizontally-disposed branch B.W.G. section 16 of the antenna system, connected across the wire reflector 15, which section will feed the reflected incoming horizontally-polarized signal beam energy to the signal (radio) receiver, connected to that branch B.W.G. section. The wire reflector 15, because its wires extend in a direction perpendicular to the electric field E_1 , will prevent transmission of any portion of the incoming signal energy with horizontal field polarization to the signal transmitter over the horizontally-disposed B.W.G. branch section 13 while allowing free transmission of the outgoing vertically polarized signals from the radio transmitter over the vertical B.W.G. branch 8 to the terminating phase plate 10 and reflector 11 of the antenna system.

The beam of a beam-waveguide antenna such as shown in FIG. 7 or FIG. 8 can be rotated by the use of any of the known antenna rotating means (not shown) for rotating the reflector 11 or 14 around the vertical axis of the vertically-disposed B.W.G. branch section 8 of the antenna system. However, if no change in the polarization of the radiation field is required, the field injected into the B.W.G. has to be rotated simultaneously. No such rotation at the feeding end of the B.W.G. is required when circularly-polarized wave beams are used.

Since the 3-decibel beam width or the gain of the antenna depends upon the diameter of the B.W.G., a transformation from small to large diameter B.W.G. sections, or vice versa, may be desirable in the beam-wave antenna systems of the invention. If very small beam widths are required, it is not necessary to redesign the entire beam waveguide to have the required large radius R . Instead, the transitions between beam-waveguide sections of different cross-sections can be performed at the end of the beam-waveguide by the expedient diagrammatically illustrated in FIG. 10 of this application (also illustrated in FIG. 9 and described in paragraph "D" beginning on page 14 of applicant's aforementioned application). In the arrangement of FIG. 10 of this application, the two sections of beam-waveguide of different cross-sections to be connected together are designated BGI and BGII. The lens L mounted between these two waveguide sections is a magnifying lens which forms an enlarged image of the last phase plate or lens of BGI at the plane of the first phase plate or lens of BGII. The diameter of L is made large enough so as not to introduce any diffraction effects by restricting the passing beam. In other words, L shall operate as an optical lens. The last phase

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plate of BGI is replaced by a lens which is of the same diameter as all the other phase plates therein but which is of different focal length which is made such that the lens images the plane of the preceding lens of the guide into the plane of the magnifying lens L . Similarly, the first phase plate or lens of BGII is replaced by one which images the plane of the succeeding lens of this guide into the plane of lens L .

In the case of the beam-waveguide antenna, the entire beam waveguide of large diameter, BGII, can be replaced by a single phase plate or lens 17, as shown diagrammatically in FIG. 11, the diameter of which phase plate or lens is equal to that of the larger diameter waveguide (BGII) and the focal length of which is equal to the distance D' of the phase plate 17 from the magnifying lens L .

The combination of the terminating phase plate 10 and the plane reflector 11 of the beam-waveguide antenna of FIG. 7 may be replaced by a parabolic reflector for performing their combined functions, as shown at 14 in FIG. 8.

If a beam-waveguide B.W.G. with the cross-sectional field configuration of FIG. 6 is used, an omnidirectional beam-waveguide antenna can be made, as shown in FIG. 12. The antenna of FIG. 12 differs from that of FIG. 7 merely in the substitution of a reflecting metal cone 18 of appropriate angle for the plate reflector 11 following the terminating phase plate 10, and the use of a cross-sectional field configuration for the B.W.G. section (branches 8 and 13) corresponding to that shown in FIG. 6. The cone 18 will reflect the outgoing conical signal beam fed thereto from the terminating phase plate 10 in all directions about the vertical axis of the cone. In the receiving condition, the cone 18 will reflect the intercepted incoming electromagnetic signal beam through the terminating phase plate 10 at one end of the B.W.G. section of the antenna over which it will be propagated confined to a substantially cylindrical shape to the radio signal receiver connected to the other end of that section.

The beam-waveguide antennas of the invention as above described not only are more efficient than the combination of a beam-waveguide and a conventional antenna in that the losses of the additional transducer or launcher and antenna feed required by the combination are eliminated, but are also less complicated, for example, in the case of rotating scanning antennas, the former do not require rotary joints such as would be required in the combination system.

Other modification of the beam-waveguide antenna system as described above and illustrated in the drawings which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. A directive antenna system comprising a section of beam-waveguide with associated means for launching therein, or receiving therefrom, a beam of high frequency electromagnetic signal wave energy, said beam-waveguide including a plurality of phase-correcting members respectively inserted at different points in the path of the propagated beam which are spaced from each other longitudinally by equal distances large in comparison to the beam radius and the beam wavelength, each of said members being adapted to produce at the point of its location a phase shift in the propagated beam such as to compensate for the usual diffractive divergence thereof occurring in transmission to that member from the preceding phase-correcting member so that the members in combination confine the propagated beam energy to a substantially cylindrical space, and means for converting the resulting cylindrical beam into a conical form for radiation into space comprising another phase-correcting member forming one termination of the beam-waveguide section and located at a distance from the next adjacent phase-correcting member equal to the mutual spacing

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between successive ones of the first-mentioned members, said other member being adapted to effect a phase-shift in the applied beam which is half that produced therein by each of said first-mentioned members.

2. A directional radiating antenna system comprising a section of beam-waveguide with associated means for launching a beam of said high frequency wave energy therein for propagation thereover, said beam-waveguide including a plurality of phase-correcting members respectively inserted in the path of the propagated beam at different points spaced longitudinally at equal intervals large in comparison with the beam radius and the beam wavelength, said members operating in combination to introduce phase shifts into the propagated beam such as to compensate for the usual diffractive expansion which would be produced therein and thus to confine the energy of the propagated beam to a substantially cylindrical space, and means to convert the resulting cylindrically-shaped beam into conical form for radiation into space in a desired direction comprising a terminating phase-correcting member for said waveguide section at a distance from the preceding phase-correcting member equal to the mutual spacing between the first-mentioned members and adapted to insert a phase-shift in the applied cylindrical beam which is equal to half that produced therein by each of the first mentioned phase-correcting members.

3. A directive antenna system for the radiation and reception of high frequency electromagnetic signal wave energy comprising in combination, a section of beam-waveguide, means for launching into, or receiving from, said waveguide section a signal beam of high frequency electromagnetic wave energy, said beam-waveguide section including a plurality of phase-correcting members respectively inserted in the path of the propagated beam at different points spaced longitudinally from each other by equal distances long in comparison to the beam radius and the wavelength of said beam, all of said members except a terminating one at one end of the line section being appropriately designed so that each resets the cross-sectional phase distribution in the propagated beam at its point of location to effectively compensate for the diffractive expansion occurring in the beam in transmission to that point from the preceding phase-correcting member, these members in combination thereby confining the energy in the propagated beam to a substantially cylindrical space, and said one terminating phase-correcting member being designed to effect a phase shift in the applied beam which is substantially half that produced therein by each of the other phase-correcting members and which will cause the applied outgoing cylindrically-shaped signal beam to be converted into a conical form for radiation into space, and the intercepted incoming signal beam to be converted into a form suitable for propagation over said waveguide section.

4. The antenna system of claim 1, in which said one terminating phase-correcting member is a dielectric lens having a focal length equal to the mutual spacing between each two successive phase-correcting members.

5. The antenna system of claim 2, in which said terminating phase-correcting member comprises a dielectric lens having a focal length equal to the mutual spacing between each two successive phase-correcting members in said guide and the cross-sectional field configuration of the beam launched into said section of waveguide is selected such as to provide maximum radiation of the beam in the forward direction.

6. An antenna system for the radiation and reception of high frequency electromagnetic wave energy comprising a mast member, a section of beam-waveguide of which at least the end portion is mounted vertically inside said mast member, means for launching an outgoing signal beam of high frequency electromagnetic energy in said waveguide section for propagation thereover, and for receiving an incoming signal beam of electromag-

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netic wave energy therefrom, said beam-waveguide including a plurality of phase-correcting dielectric lenses respectively inserted in the path of the propagated beam at different points with the same longitudinal spacing between each two successive lenses, which is large compared to the radius of the propagated beam and very large compared to the beam wavelength, all of said lenses except the uppermost, terminating lens having a focal length of $D/2$, where D is equal to the mutual spacing between successive lenses, and operating in combination to produce phase shifts in the propagated beam energy such as to compensate for the diffractive expansion of the beam between lenses and thus to confine the energy of the propagated beam within a substantially cylindrical space, said terminating lens having a focal length of D and operating to transform the cylindrically-shaped outgoing signal beam to conical form and to transform an applied incoming signal beam to a form suitable for propagation over said beam-waveguide section, and a plane reflector mounted above said terminating lens and suitably angularly-disposed with respect to the longitudinal axis of the vertical portion of said beam-waveguide section for reflecting the conically-shaped outgoing signal beam received from said terminating lens into space in a desired direction, and for reflecting the intercepted portion of an incoming signal beam through said terminating lens into said beam-waveguide section for propagation thereover to said receiving means.

7. The antenna system of claim 6, in which said beam-waveguide section has a vertically disposed branch and a horizontally disposed branch connected by a 90° bend including a second angularly disposed reflector for reflecting the beam wave energy therebetween.

8. An antenna system for the radiation and reception of high frequency electromagnetic wave energy comprising a mast member, a section of beam-waveguide of which at least one end portion is mounted vertically inside said mast member, means for launching an outgoing signal beam of high frequency electromagnetic wave energy in said section for propagation thereover, and for receiving an incoming signal beam of electromagnetic wave energy propagated over said section, said beam-waveguide section including a plurality of phase-correcting dielectric lenses respectively inserted in the path of the propagated beam at different points with the same longitudinal spacing between each two successive lenses which is large compared to the radius of said beam and its wavelength, certain of said lenses having a focal length of $D/2$, where D is equal to the mutual spacing between successive lenses, each lens operating to produce a phase shift in the beam such as to compensate for its diffractive expansion in transmission from the preceding lens and thus to confine the energy of the propagated beam within a substantially cylindrical space and means to transform the outgoing signal beam energy emerging from said one end portion of said section to conical form and to reflect it in that form into space in a desired direction, and to reflect the intercepted portion of an incoming signal beam into said one end portion of said waveguide section in suitable form for propagation thereover to said receiving means.

9. The antenna system of claim 8, in which said transforming and reflecting means comprise a parabolic reflector suitably mounted above the uppermost dielectric lens in said one end portion of said beam-waveguide section and operating to perform both its transforming and reflecting functions.

10. The antenna system of claim 8, in which said transforming and reflecting means comprise a terminating lens having a focal length of D in said one end portion of the beam-waveguide section operating to transform the cylindrically-shaped outgoing signal beam to conical form, and a reflecting metal cone of appropriate angle mounted above said terminating lens and operating to provide omnidirectional radiation of the outgoing con-

cally-shaped signal beam transmitted thereto through said terminating lens, and to reflect the intercepted portion of an incoming signal beam into said waveguide section through said terminating lens, the cross-sectional configuration of the beam launched into said section of waveguide being selected such as to provide a maximum radi-

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ation of the outgoing beam at a given angle with respect to the longitudinal axis of said waveguide section.

References Cited in the file of this patent

UNITED STATES PATENTS

2,588,610 Boothroyd et al. ----- Mar. 11, 1952