July 29, 1952 L. W. ALVAREZ 2,605,413

ANTENNA SYSTEM WITH VARIABLE DIRECTIONAL CHARACTERISTIC

Filed Nov. 10, 1943 5 Sheets-Sheet 1

FIG. 1A

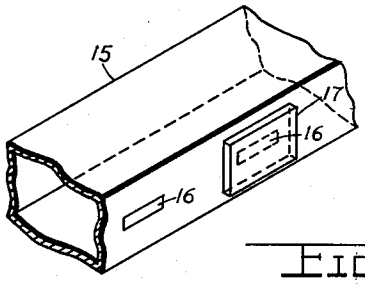


FIG. 1

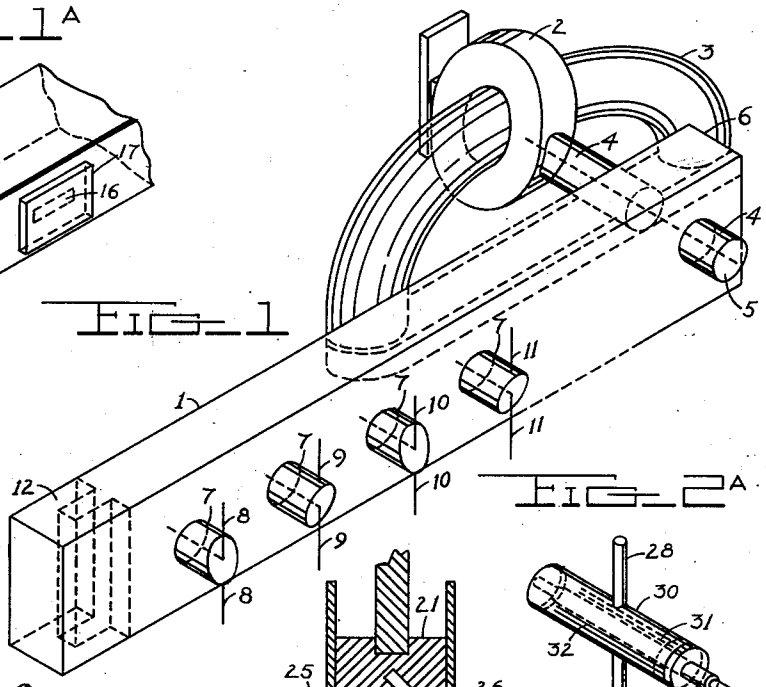


FIG. 2A

FIG. 4

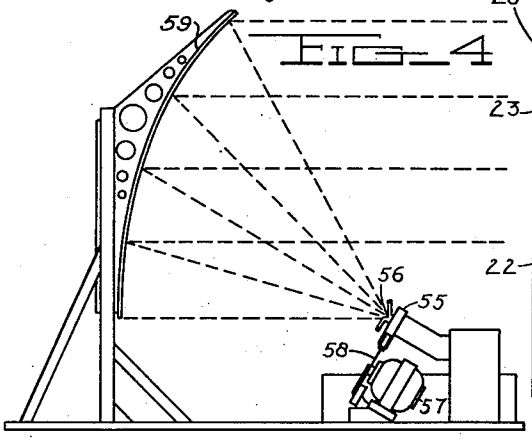
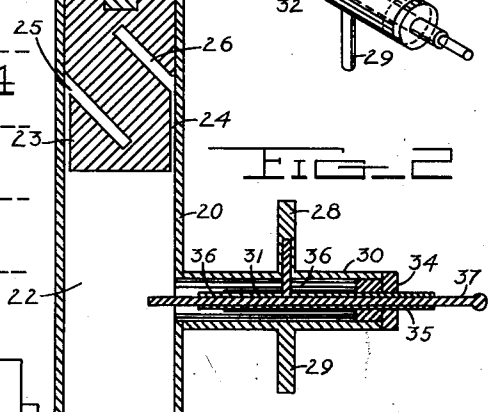


FIG. 2



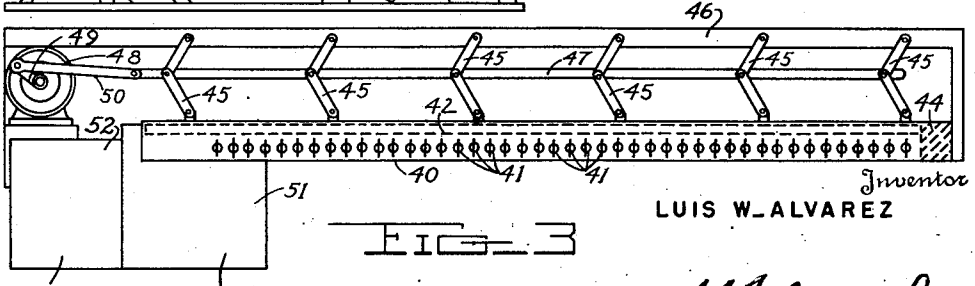


FIG. 3

RECEIVER TRANSMITTER

Inventor
LUIS W. ALVAREZ

By

Attorney

July 29, 1952 L. W. ALVAREZ 2,605,413

ANTENNA SYSTEM WITH VARIABLE DIRECTIONAL CHARACTERISTIC

Filed Nov. 10, 1943 5 Sheets-Sheet 2

FIG. 6

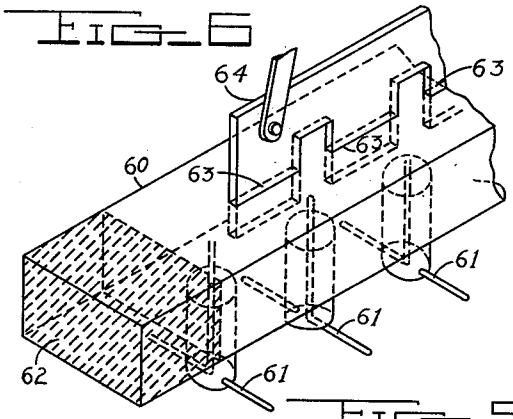


FIG. 5

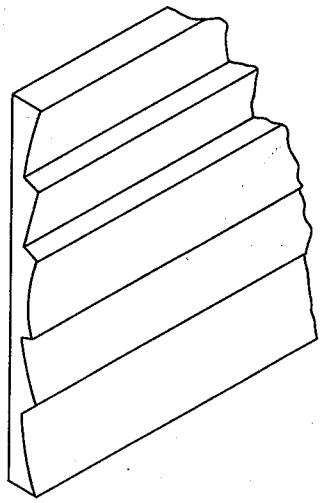


FIG. 9

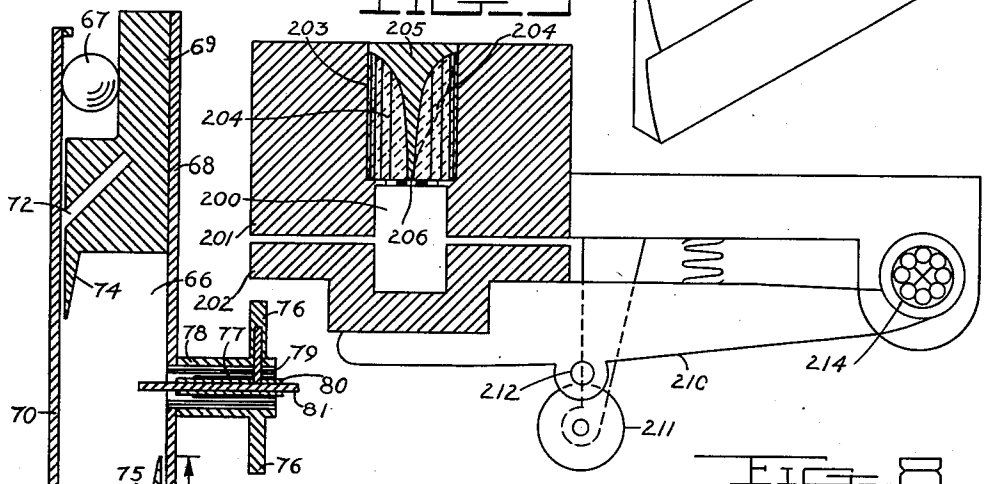


FIG. 8

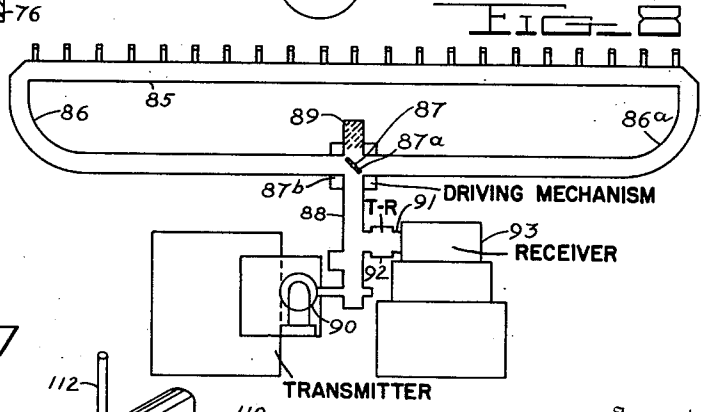


FIG. 7

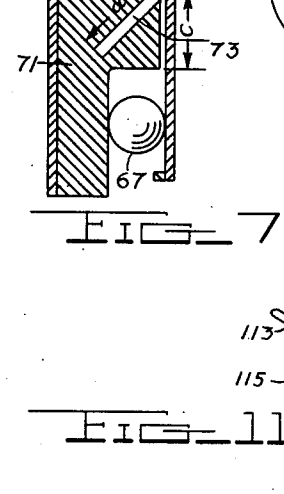
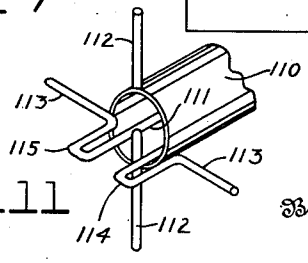


FIG. 11



Inventor
LUIS W. ALVAREZ

By

Attorney

July 29, 1952 L. W. ALVAREZ 2,605,413

ANTENNA SYSTEM WITH VARIABLE DIRECTIONAL CHARACTERISTIC

Filed Nov. 10, 1943 5 Sheets-Sheet 3

FIG. 10

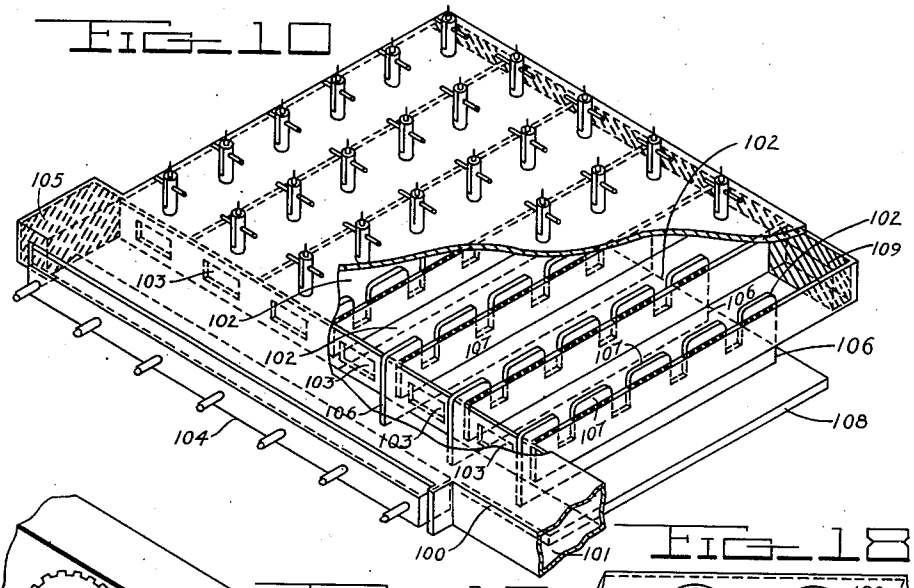


FIG. 18

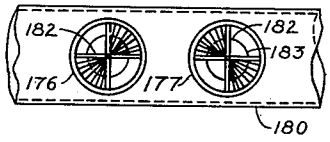


FIG. 12

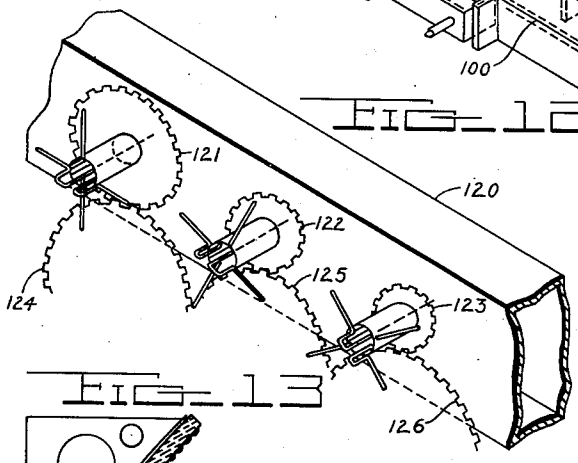


FIG. 16

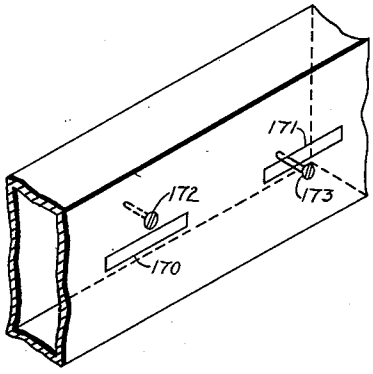


FIG. 13

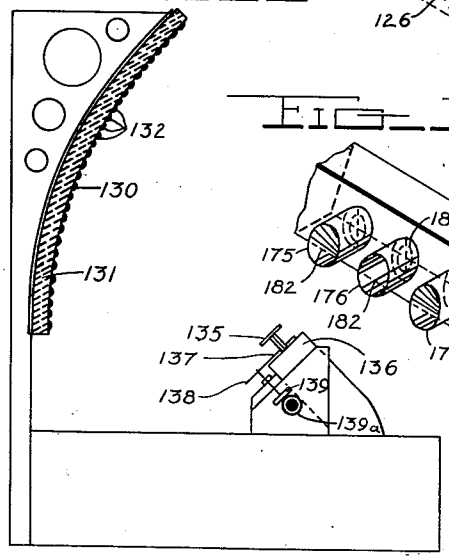


FIG. 17

Inventor
LUIS W. ALVAREZ

By J. J. Fitzgerald
Attorney

July 29, 1952 L. W. ALVAREZ 2,605,413

ANTENNA SYSTEM WITH VARIABLE DIRECTIONAL CHARACTERISTIC

Filed Nov. 10, 1943 5 Sheets-Sheet 4

FIG. 14

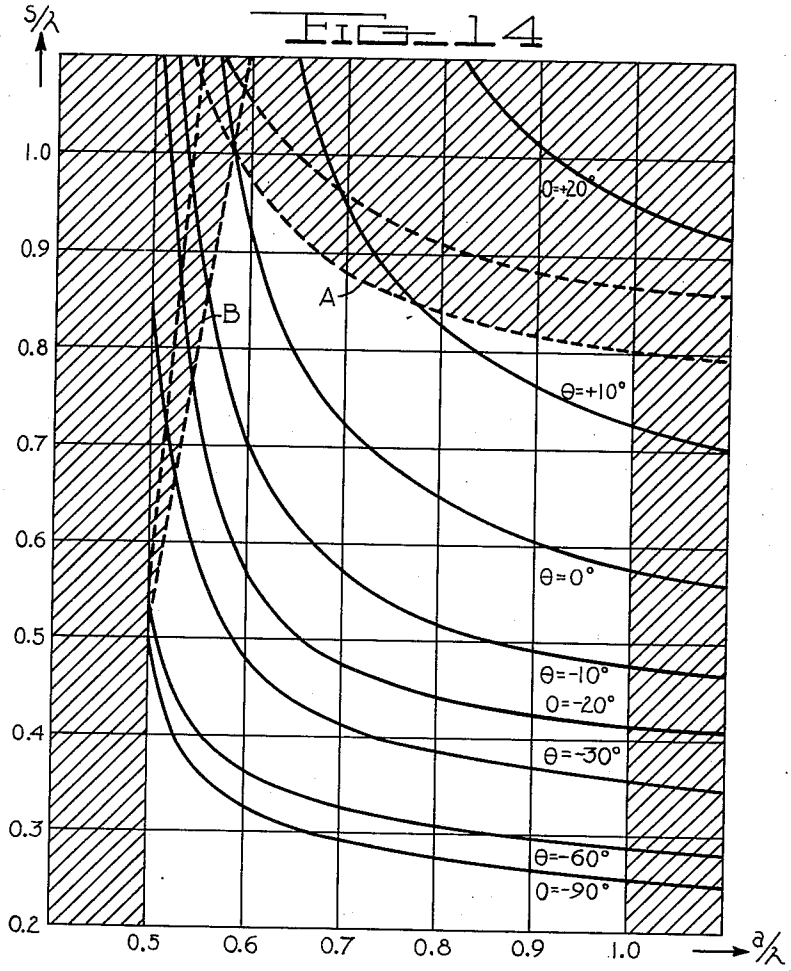
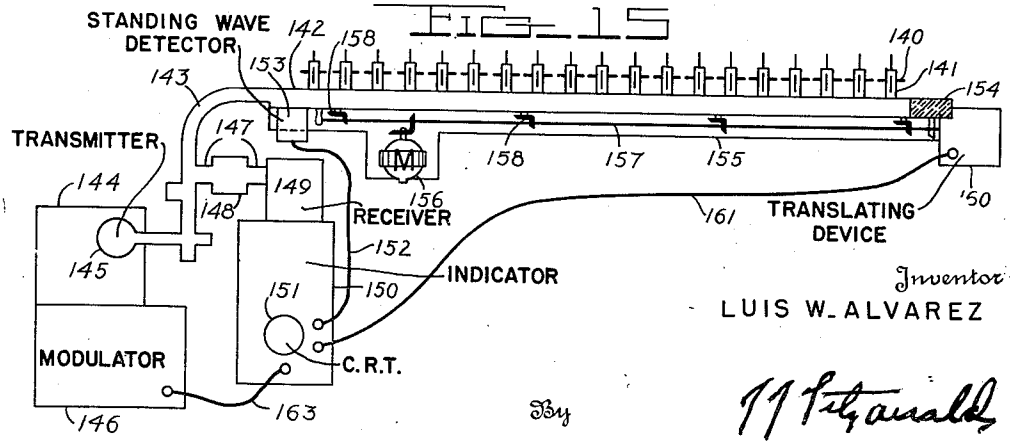


FIG. 15



Inventor
LUIS W. ALVAREZ

By J. J. Fitzgerald

Attorney

July 29, 1952 L. W. ALVAREZ 2,605,413

ANTENNA SYSTEM WITH VARIABLE DIRECTIONAL CHARACTERISTIC

Filed Nov. 10, 1943 5 Sheets-Sheet 5

FIG. 19

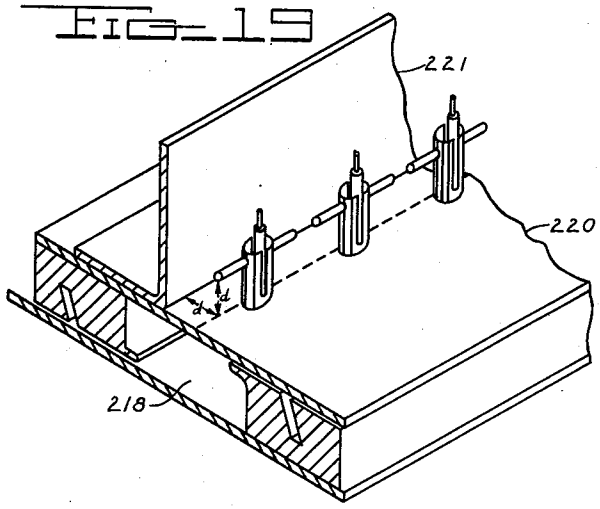


FIG. 20

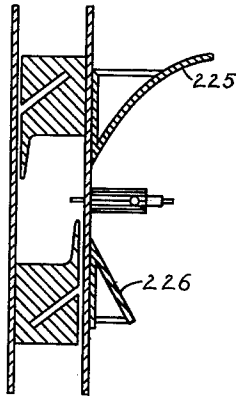


FIG. 21

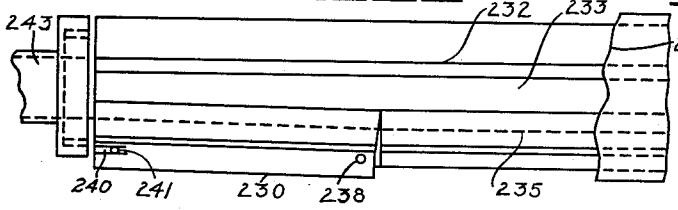


FIG. 22

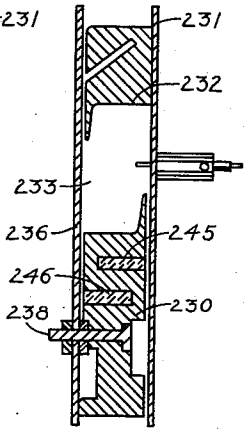


FIG. 23

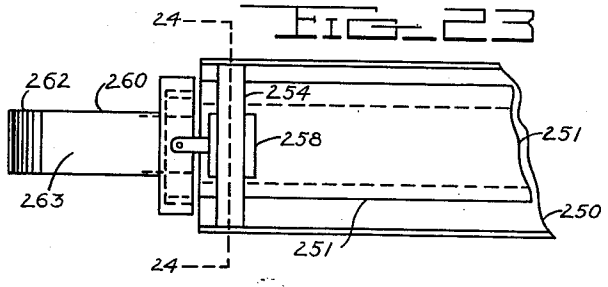
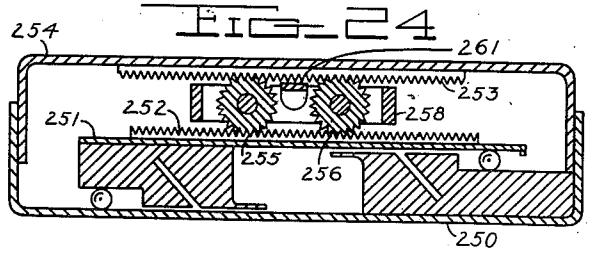


FIG. 24



Inventor
LUIS W. ALVAREZ

By

Attorney

Patented July 29, 1952 2,605,413

UNITED STATES PATENT OFFICE

2,605,413

ANTENNA SYSTEM WITH VARIABLE DIRECTIONAL CHARACTERISTIC

Luis W. Alvarez, Belmont, Mass., assignor, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Application November 10, 1943, Serial No. 509,790

48 Claims. (Cl. 250—33.63)

1

This invention relates to directive antenna systems for transmission and reception of high-frequency radio waves particularly to directive antenna systems with variable directional characteristics in at least one plane which characteristics may be adjusted or varied in a relatively continuous manner independently of the physical location in space of the structure.

I have found that a hollow pipe wave guide is particularly useful for feeding phased radiating and receiving antenna arrays adapted to have their directional characteristics changed by a change of phasing in the feed line, because such change of phasing can be accomplished in a relatively simple manner by changing the wave length of the oscillations in the hollow pipe wave guide. The simplest form of phased radiating array fed by a hollow pipe wave guide is the provision of a series of slots or apertures in the wall of the wave guide spaced by a suitable distance, normally in the neighborhood of the wave length of the oscillations in the wave guide. Because the wave length of the oscillations in the wave guide is normally greater than that in unconfined space, the radiation from an arrangement such as that just mentioned will take place in several sharply defined directions, corresponding to the different orders of spectra formed by a diffraction grating. In order that only the central beam may be radiated it is necessary that the slots in the wave guide should be separated by a distance less than the wave lengths in unconfined air or else that the radiating elements should themselves have directive characteristics sharp enough to suppress the extra order beams. The former alternative may be realized by introducing dielectric material in the wave guide which has the effect of shortening the wave length in the wave guide, and by some other similar methods. Such arrangements, however, often make it difficult to provide the desirable variation of the wave length in the wave guide for varying the orientation of the radiated beam.

By the present invention I have provided for close spacing of wave-guide-fed radiating elements by providing radiating elements alternate units among which are caused to be reversed in phase. When such elements are provided, it is possible to locate the radiating elements so as to be fed from the wave guides at points separated by a half-wave length in the guide, which half-wave length is usually shorter than the full wave length in air even for air-filled hollow pipe wave guides. Since the hollow pipe wave guide may then be air-filled, it then becomes relatively simple to change the wave length of the waves therein.

2

The simplest form of radiating elements readily amenable to a reversal of polarity in the feed is a dipole fed by a short two-conductor transmission line from the wave guide which provides the power for the array and also provides the phasing. I have worked out many forms of readily variable phased arrays employing dipoles mounted upon wave guides and constituting various forms of the present invention which are described below and illustrated in the attached drawings, in which:

Fig. 1 is a perspective view illustrating the general principles of the construction and operation of antenna systems in accordance with the present invention;

Fig. 1A is a perspective view, party broken away, illustrating another method of obtaining a single broadside beam from an air-filled wave guide by introducing a phase reversal at alternate radiating elements;

Fig. 2 is a cross section illustrating an improved form of dipole antenna for use in an arrangement such as that of Fig. 1 and Fig. 2A gives a perspective view of the same, omitting the associated hollow pipe wave guide;

Fig. 3 shows, in elevation, an antenna system according to the present invention including means for continuously varying the phasing of the array;

Fig. 4 is an end view illustrating the use of a arabolic cylinder reflector for further concentration of the beam provided by the rest of the antenna system in accordance with the present invention;

Fig. 5 is a perspective view, partly broken away, illustrating another form of reflector adapted for use in a system similar to that shown in Fig. 4;

Fig. 6 is a perspective view, partly broken away, of an antenna system in accordance with the present invention illustrating another method of varying the directional characteristics without physically varying the physical position of the radiating elements;

Fig. 7 shows, in cross section, still another form of the present invention;

Fig. 8 is a plan view, partially diagrammatic, of an improved form of the present invention for relatively wide angle variation in the orientation of the directive maximum of the antenna system;

Fig. 9 shows, partly in cross-section, a form of the invention adapted for variation of the orientation of the directive maximum of the antenna system with rapidity over an angle of about 10°;

Fig. 10 is a perspective view, partly broken away,

illustrating an antenna system in accordance with the present invention adapted for variation of the orientation of the directive characteristics of the antenna system about two different axes without physical movement of the radiating elements;

Fig. 11 is a perspective view, partly broken away, of a radiating and receiving element adapted for use in connection with circularly polarized radiation;

Fig. 12 is a perspective view, partly broken away, illustrating a modified form of the present invention employing radiating elements of the type shown in Fig. 11;

Fig. 13 is an end view of an apparatus such as that shown in part in Fig. 12 arranged to cooperate with a special type of auxiliary reflector;

Fig. 14 is a diagram illustrating the scanning characteristics of forms of the invention such as those illustrated in Figs. 2 and 7;

Fig. 15 is a plan view of another possible form of apparatus in accordance with the present invention, and

Fig. 16 is a perspective view, partly broken away, illustrating still another method of obtaining a single broadside beam from an air-filled wave guide by introducing a phase reversal at alternate radiating elements.

Figs. 17 and 18 illustrate, respectively in perspective and in elevation, still another arrangement for obtaining a single broadside beam from an air-filled feed wave guide by introducing an additional relative phase reversal at alternate radiating elements;

Figs. 19 and 20 are cross-sectional views illustrating arrangements for concentrating radiation somewhat with respect to directions in a plane perpendicular to the axis of the antenna system;

Figs. 21 and 22 illustrate an arrangement for matching a scanning antenna according to this invention to a wave guide leading to a transmitting and receiving system, Fig. 21 being a front view, partly broken away, and Fig. 22 being a cross-section, and

Figs. 23 and 24 illustrate another arrangement for matching a scanning antenna according to this invention to a wave guide leading to a transmitting and receiving system, Fig. 23 being a back view, partly broken off, and Fig. 24 being a cross-section along the line 24—24 of Fig. 23.

One object of this invention is to provide directive antenna systems having more sharply directive properties in at least one plane than the more conventional antenna system used for very short waves. Another object of the present invention is to provide highly directive antenna systems the orientation of the directive patterns of which may be continually varied without actual motion of the radiating elements or of any associated reflectors. Other objects of the invention will be apparent from the reading of this specification.

Fig. 1 shows a rectangular wave guide pipe 1 fed with electromagnetic oscillations of very high frequency—for example about 3000 megacycles per second—produced by a generating device 2 which may be a magnetron type of transmitting tube operated intermittently by means (not shown) to produce short-duration high-intensity pulses of energy. A magnet for producing the magnetic field required by the magnetron tube is shown at 3. The hollow pipe wave guide 1 is excited by the generating device 2 through a coaxial conductor transmission line 4 the central conductor of which passes centrally through the wave guide 1 parallel to its shorter cross-sectional dimension, so that the $TE_{1,0}$ mode of oscillation may readily be excited. Beyond the wave guide 1 the transmission line 4 is short-circuited at a suitable location by a terminal plug 5 and likewise the wave guide 1 is short-circuited by the wall 6 at a suitable location on one side of the transmission line 4.

The wave guide 1 is adapted to transmit the $TE_{0,1}$ mode of oscillation excited by the transmission line 4 without substantial interference arising from the presence of other modes. Such operation is obtained by suitably arranging the dimension of the wave guide 1. For this purpose the cross section of the wave guide 1 is preferably approximately 0.3 by 0.7 wave lengths, referring to the free-space wave length of oscillations of the frequency in question. As is well known, the wave length of the oscillation in the pipe 1 will be greater than the said free-space wave length. The part of the pipe 1 immediately to the left of the transmission line 4 is shown in dotted lines in order to indicate that the pipe may be, and preferably is, a great deal longer than can be conveniently illustrated in Fig. 1. If it is desired to operate the apparatus of Fig. 1 for receiving as well as for transmitting, a branch wave guide may be connected with the pipe 1 near its right-hand end, preferably on the back side, for connection of the pipe 1 to a receiving apparatus, said branch pipe being preferably provided with a protective electrical breakdown device adapted to short-circuit the branch pipe while the generating device 2 is in operation. Such short circuit may, in accordance with known principles, be made to occur in such a location that it does not interfere with the transmission of electromagnetic waves along the pipe 1.

At regular intervals along the length of the pipe 1, said intervals being less than the said free-space wave length of oscillations of the frequency in question, small branch wave guides 7, of the coaxial-conductor type, are provided on one of the broader walls of the pipe 1. The coaxial-conductor transmission lines 7 are coupled to the wave guide 1 by the projection of the inner conductors of the respective coaxial-conductor guides into the hollow pipe wave guide 1. Since this projection of the said inner conductors is in a direction parallel with the electric vector of the $TE_{1,0}$ wave in the pipe 1, the coaxial-conductor guides will be excited by the wave in the pipe 1 and the relative phase in which the several coaxial conductor guides are excited will depend upon the phase shift of the electrical vector of the $TE_{1,0}$ wave along the length of the wave guide 1, in other words upon the electrical length of the intervening portions of the wave guide 1. Thus if the spacing between centers of adjacent coaxial conductor guides 7 is equal to a half-wave length of the $TE_{1,0}$ wave in the guide 1, the said coaxial conductor guides 7 will be excited exactly in phase opposition.

Each of the coaxial conductor guides 7 terminates in a dipole antenna. As shown in Fig. 1 at 8, 9, 10 and 11, these dipole antennas are each oriented parallel to the broader cross-sectional dimension of the wave guide 1 and all of these dipoles are at the same distance from the nearer broad wall of the wave guide 1, to which they are parallel. If desired, the dipole may be oriented parallel to the longitudinal axis of the wave guide (e. g. Fig. 15), or at 45°, etc., but they should in each case be substantially parallel to each other.

The distance between the dipoles and the outer surface of the wave-guide wall is preferably made to be such that reflection of energy from the

wave-guide wall will provide a substantial reinforcement of radiation from the dipoles in the directions away from the wave guide near the plane passing through the axis of the array and perpendicular to the reflecting wave-guide wall. One might expect the most favorable distance for this purpose to be a quarter-wave length, or some other small odd number of quarter-wave lengths, and in fact such a distance is quite satisfactory. It is found, however, that other distances may well be somewhat more favorable, and particularly that distances considerably less than a quarter-wave length appear to be especially favorable for the desired type of reflection. On the other hand, distances approximating an integral number of half-wave lengths are decidedly unfavorable. Actually, the gain of the individual antenna elements in the forward direction is not of great importance since the length of the array provides such a great deal of gain while providing the desired resolution.

The dipole antennas 8, 9, 10 and 11 and other dipole antennas (not shown) that may be located upon the portion of the wave guide pipe 1 shown in dotted lines, are not oriented entirely alike, however, for alternate dipoles are effectively reversed, which is to say that while the upper arm of the dipoles 8 and 10 is connected to the central conductor of the corresponding coaxial structure 7 and the lower arms of the dipoles 8 and 10 are connected to the outer conductor of the structures 7, in the case of the dipoles 9 and 11 it is the lower arm that is connected to the central conductor of the corresponding structure 7 and the upper arm of the dipole that is connected to the outer conductor of the structure 7. Thus, if for instance the structures 7 and consequently the associated dipoles, are spaced by one-half of the wave length of the oscillations in the wave guide 1, then, although the alternate members of the series of coaxial structures 7 will be driven in relative phase opposition, the alternate reversals of the dipole connection will compensate for such phase opposition and all the dipoles will be excited in phase. In consequence a directive beam of radiation greatly concentrated in a plane perpendicular to the axis of the wave guide 1 will be formed. A similar directional characteristic will be obtained for reception purposes. If the length of the array is large, the concentration of the beam in such plane will be very great, it being entirely practical to obtain a beam having a width of one-half a degree between half-power points with antenna structures of reasonable proportions. Within the said plane in which the beam tends to be concentrated as aforesaid, the radiation is fairly broadly distributed in direction. The reflecting effect of the wall of the wave guide 1 does provide some directivity, the half-power width of the beam in a plane perpendicular to the axis of the wave guide 1 being on this account about 60°, usually. The beam may be further concentrated in this plane by the use of reflectors as shown in Figs. 4 and 5 or by distributing the dipole radiators in two directions as shown in Fig. 10. Some concentration of this sort may also be achieved by using reflecting strips mounted on the feed wave guide, as shown in Figs. 19 and 20 and further described below.

If the spacing between centers of the coaxial structures 7 is not 180 electrical degrees (a half-wave length of the oscillations in the wave guide 1) but some other value, preferably between about 140° and 220°, the reversal of alternate dipole connections still cooperates in the formation of a single sharply defined beam by causing successive dipoles to have a progressive phase shift so that a beam is radiated at an angle to the axis of the wave guide 1 which is determined in accordance with well-known principles by the phase difference between successive dipoles.

In the arrangement of Fig. 1 energy proceeding to the left in the wave guide pipe 1 is diminished by amounts of energy abstracted by the coaxial structures 7, so that only a small amount, which may be 5 per cent or 10 per cent, continues to travel down the pipe 1 beyond the last of the coaxial structures 7. Although this remaining amount of energy is usually relatively small, it should nevertheless not be allowed to build up standing waves in the wave guide 1 as a result of reflection from the left-hand end of the said wave guide if such reflection effect can be prevented. Consequently the left-hand end of the wave guide 1 is preferably filled with a suitable absorbing material, which may be cotton gauze impregnated with graphite. The location of the absorbing material is indicated by the dotted line at 12. The absorbing material is preferably chosen in accordance with well-known principles to provide a very small amount of reflection, if any. Instead of an absorbing material filling the whole end portion of the wave guide 1, a suitable resistor interposed across the central part of the wave guide 1 and parallel to the narrow cross-sectional dimension thereof may be employed.

The coaxial structures 7 which support and feed the dipoles 8, 9, 10, 11, and so on, may be arranged in any of a number of ways. In the form of the invention illustrated in Fig. 1 the space between the two coaxial conductors of the said structures is preferably filled with a solid dielectric material such as polystyrene in order to support the inner conductor relative to the outer conductor. Such material tends to shorten the wave length inside the coaxial conductor structure, but this is not important since an equal effect will take place in each of the structures 7. In the form of apparatus shown in Fig. 1 the ends of the structures 7 which terminate in the dipoles 8, 9, 10, 11 and so on are obliquely terminated, in order to provide clearance between the dipole arm connected to the inner coaxial conductor and the nearby portion of the outer coaxial conductor, so that the dipole arms of each dipole may be properly aligned with each other.

The center conductor of the coaxial structures, instead of being supported as in Fig. 1 by dielectric material, may be supported by continuing the coaxial structures beyond the dipoles in such a manner as to provide a resonant short-circuited stub-support, the necessary aperture being made in the outer conductor for the passage of the dipole arm connected to the inner conductor. Still further modification of the manner of exciting the dipole is possible with improvement in result and I have shown in Figs. 2, 2A and 7 certain preferred forms of structures for exciting dipoles in apparatus of the present invention, which are described in detail below.

Fig. 1A shows another method of obtaining the phase reversal required for obtaining a single narrow beam from a series of spaced radiators fed from an air-filled hollow pipe wave guide. A portion of a rectangular hollow pipe wave guide is shown at 15 which is adapted to be excited in the $TE_{0,1}$ mode. The radiating elements are in this case simply slots 16 in one of the narrower walls of the wave guide. The centers of the slots are

spaced preferably between 140 and 220 electrical degrees apart. Alternate slots are covered by plates of rutile, such as the plate 17, in which the wave length of the radiation is very much shorter than the wave length of such radiation in air. The plate 17 is of such thickness that the phase of the radiation is retarded 180° with respect to the phase that would have been obtained had the plate been absent. For the very high frequencies here concerned the rutile plate 17 should have a thickness of the order of magnitude of 6 mm. The plate 17 may be conveniently cemented to the wall of the wave guide 15. In the arrangement illustrated in Fig. 1A it is possible that the radiation resistance of the covered slot may be somewhat different from that of the uncovered slot, so that the suppression of undesired side beams may not be complete. To some extent it is possible that this may be compensated for by providing structures in the wave guide 15, between the slot locations, which have the effect of shunt reactances. Such arrangements, in accordance with known principles, may serve to equalize the energy transfer through the two different type of slots. This phase reversal by means of a suitable dielectric plate may also be used with other forms of slot arrays associated with wave guides, such as arrays of transverse slots cut in the broad side of a rectangular pipe, and so on. The slots in each case are located so as to intercept oscillatory currents associated with the transmitted oscillations. Transverse slot arrays modified as in Fig. 1 may also be constructed with a coaxial-conductor wave guide.

Fig. 16 shows another arrangement for providing a relative phase reversal in connection with the radiation from slots cut in a hollow pipe wave guide. In Fig. 16, the slots 170, 171 are cut in the broad side of a rectangular wave guide, preferably in the center portion thereof. Normally no radiation, or very little radiation, will occur from slots so located, but screws 172 and 173 are inserted into the wave guide to distort the field within the wave guide so that an electric field will appear across the slot. The screw 172 is on one side of the slot 170, whereas the screw 173 is on the other side of the slot 171, so that the field distortion is geometrically in opposite directions for successive slots, thereby providing the desired phase reversal.

Still another method for providing a relative phase reversal in connection with radiation from spaced locations along a wave guide is shown in Figs. 17 and 18. The radiation in this case takes place from short cylindrical branch wave guides 175, 176 and 177 and so on, supported on one of the broad sides of the rectangular feed wave guide 180. In order that the branch wave guides 175, 176 and 177 may transmit energy without occupying too great a portion of the wall of the wave guide 180, the cylindrical wave guides may be filled with a dielectric material such as polystyrene or paraffin or "polythene." The phase reversal is provided by means of a twisted septum or partition 182, which is given a quarter twist. The polarization of the oscillations in the cylindrical guide will follow the twist imposed by the septum. The twist is made in the opposite direction in alternate branch wave guides, so that in the wave guides 175 and 177 it is in one direction and in the wave guide 176 it is in the opposite direction. Thus between the ends of the wave guides 176 and 177 there is provided a 180° phase shift as a result of the oppositely carried-out 90° twist. This cooperates with the phase shift produced by the length of the guide 180 between the guides 176 and 177, which is usually in the general neighborhood of 180°, say somewhere between 140° and 220°, to provide a desirable type of antenna directive characteristic as elsewhere fully described herein.

If the branch guides are filled with solid dielectric material, this may conveniently serve to hold the septa, about which the dielectric may be molded, in position.

The degree of coupling between the main guide and the branch guides is determined by the size and shape of the apertures 183 through which the guides connect. The system of antenna organization shown in Figs. 17 and 18 is of particular utility at very short wave lengths, such as 1 cm., at which other types of construction might involve too much fine work.

One particularly useful form of apparatus employing the type of organization just described is shown in Fig. 9 and described below.

In order to simplify the illustration, no means were shown in Figs. 1 and 1A for varying the phasing of the radiating elements. An important feature of the invention lies in the fact that the phasing of the radiating elements of an antenna system in accordance with the present invention may be readily varied either continuously or intermittently without altering the frequency of operation or the relative physical location of the said radiating elements. This important feature of the invention arises out of the fact that the radiating elements are fed from a wave guide in which the velocity of phase propagation (hence the wave length for a given frequency) may be varied. In contrast to the variation of the frequency of operation, which is very difficult because high-power generators of very high frequencies such as high-power magnetrons are extremely difficult to manufacture in tunable form and because variation of the frequency of operation would require tuning of the receiver of the system as well as of the transmitter, it is found in connection with this invention that the variation of the velocity of phase propagation in a hollow pipe wave guide may be made both electrically and mechanically practical and simple.

Fig. 2 shows in cross section a hollow pipe wave guide adapted for varying the wave length of oscillations at a given frequency within the wave guide, together with one of the dipoles driven by the hollow pipe wave guide and its associated feeding and supporting structure. In Fig. 2 the power distributing wave guide is formed of a channel-shaped structure 20 constituting three walls of the wave guide and a plunger member 21 forming the fourth wall of the wave guide, the wave guide being generally indicated at 22. The plunger 21 is adapted to slide up and down within the channel member 20 thus varying the broader cross-sectional dimension of the wave guide 22 and consequently varying the wave length of oscillations in the wave guide in accordance with the relation

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}}$$

The plug structure 21 fits quite snugly in the channel structure 20 at its upper end, but its lower portion is kept at a small clearance from the channel structure 20 in order that a suitably resonant cavity may be formed along each of the corner edges of the wave guide 22 formed by the

presence of the plunger 21 in the channel structure 20. These cavities are adapted to produce a very low radio-frequency impedance between the lower face of the plunger 21 and the immediately adjacent portion of the channel structure 20, by virtue of the fact that the cross-sectional electrical length is substantially a half-wave length. The resonator cavities comprise the narrow channels or clearance spaces 23 and 24 and the branch channels 25 and 26. The branch channels 25 and 26 have a depth of an electrical quarter-wave length and the distance between the mouth of the branch channels to the wave guide corner where the clearance spaces 23 and 24 connect with the wave guide 22 is likewise an electrical quarter-wave length. The channels 25 and 26 being short-circuited at their closed ends, a low impedance will be presented at the wave guide corner. Moreover, substantially no voltage will occur between the plug structure 21 and the channel structure 20 where these two structures are in contact, so that contact losses are kept at a minimum.

The form of dipole shown in cross section in Fig. 2, together with its associated feeding and supporting structure is particularly well adapted for the construction of antenna systems in accordance with the present invention. The dipole and its associated supporting structure is illustrated in a perspective view in Fig. 2A. The dipole arms 28 and 29 are both supported on a tubular member 30 which is provided with two longitudinal slots 31 and 32 at approximately 90° around the circumference of the tubular member 30 from the positions of the dipole arms 28 and 29. The outer end of the tubular member 30 is closed by a plug 34 which supports a coaxial inner tubular member 35. The tubular member 35 is connected directly with the dipole arm 28 by means of a pin 36 which in addition to providing the aforesaid electrical connection also furnishes additional support for the tubular member 35. A rod 37 is tightly but slidably fitted into the tubular member 35 so as to project beyond its inner end and beyond the end of the tubular member 30 into the wave guide 22.

The plug 34 also closes off the outer end of the slots 31 and 32. These slots each have a total length of substantially an electrical half-wave length, so that the tubular member 30 is effectively divided into upper and lower segments the central portions of which may be excited so that a radio-frequency voltage appears between them. Such excitation is provided by energy picked up by the rod 37 where it projects into the wave guide 22 and impressed upon one segment of the resonant portion of the tubular structure 30 through the pin 36. The radio-frequency is then fed to the dipole 28, 29 which thereupon radiates the energy. The intensity of the excitation of any particular dipole (in effect, the tightness or looseness with which the dipole is coupled to the wave guide 22) may be adjusted by varying the longitudinal position of the rod 37. The various individual dipoles may be thus adjusted for uniform excitation or they may be adjusted for any desired pattern of excitation, for instance a pattern in which the dipoles nearer the center of the array are more intensely energized than the dipoles nearer the ends of the array, an arrangement which tends to reduce the amplitude of the side lobes which usually appear in addition to the main beam.

Fig. 3 illustrates the manner in which a wave guide of variable width such as that shown in Fig. 2 may be arranged for continuous variation of the orientation of the directional maximum of the antenna system. With an arrangement similar to that of Fig. 2 the directional maximum of the antenna characteristic may be swung through an angle of about 30° or more, as more fully described in connection with Fig. 14. The extent of beam deviation devices of this type is limited at one extreme by the fact that excessive narrowing of the wave guide 22 by depression of the plunger 21 is likely to bring the dimensions of the wave guide to the critical dimensions for the frequency in question or undesirably close to such critical dimension, and in the other direction by the fact that widening of the wave guide 22 by raising the plunger 21 beyond a certain amount introduces the possibility of an undesired multiplicity of modes of oscillation in the wave guide. Moreover, the resonators 23, 25 and 24, 26, since they operate in the $TE_{1,0}$ mode, are somewhat sensitive to changes in the electrical dimensions of the wave guide 22 and will furnish the desired apparent short circuit at the corners of the wave guide only for a certain range of variation of such electrical dimensions.

In Fig. 3 the feed wave guide is shown at 40 the dipole array is shown at 41. The wave guide 40 is terminated at one end by absorbing material located as shown at 44. One side of the wave guide 40 is formed by the plunger indicated by dotted lines at 42, which corresponds with the plunger 21 of Fig. 2. The plunger 42 is actuated by a number of toggle links 45 suspended from a frame 46 and operated together by a rod 47, so that the plunger 42 is moved vertically and remains parallel to the bottom of the wave guide 40. The main body of the wave guide 40 is fixed to the frame 46 at its outer extremity. A suitable restraining guide or bearing surface (not shown) is provided to prevent the plunger 42 from moving longitudinally when the toggles 45 are actuated. The rod 47 is reciprocated longitudinally by the motor 48 acting through the crank 49 and the link 50. The motor is preferably caused to revolve relatively slowly, such as at a rate of one revolution every few seconds. The actuating mechanism for the toggles 45 is preferably so arranged so that in one revolution of the crank 49 the toggles are first pulled to one side, then returned to center and then pushed to the other side and then again returned to center, so that four complete sweeps, two in each direction, are accomplished for each revolution of the motor. When the driving mechanism for the toggles is operated as aforesaid the characteristic motion of the toggles cooperates with the type of reciprocating motion furnished by the crank 49 and the link 50 to provide a desirable sweep characteristic.

The transmitter and receiver of the system and their associated apparatus are indicated in a general way on Fig. 3 by the boxes 51 and 52. It is to be understood that the motor 48 or the scanning mechanism should be connected, either electrically or mechanically, with some kind of device (not shown) for furnishing to the receiver an indication of the instantaneous orientation of the antenna system directional characteristic in order that this information may be correlated with other information obtained from received signals. Apparatus of the type here shown is of particular utility in connection with radio-echo location and detection apparatus which is adapted to transmit short-duration high-energy

pulses of high-frequency oscillation and to pick up echoes of such pulses during the intervals between pulses.

The apparatus of Fig. 3 without further cooperating elements is adapted to concentrate the radiation and the reception sensitivity of the antenna system only in a cone which has the axis of the wave guide 40 for its axis and which passes over into a plane perpendicular to the axis of the wave guide 40 when the dipoles are all operating in phase. As previously pointed out, some concentration of the sheet of radiation is produced and in the case of dipoles transverse to the axis of the array the portion of the beam in which intensity exceeds the half-power level is concentrated by the fact that the nearer wall of the wave guide 40 parallel to the dipoles acts as a reflector, into an angle of 60° about the axis of the wave guide. Further concentration of the beam may be obtained by the use of an auxiliary mirror as shown in Fig. 4, or by means illustrated in Figs. 19 and 20, or by both means together. By arrangements including a mirror of the type shown in Fig. 4 a beam may readily be concentrated into the form of a relatively thin pencil. If desired, the concentration in the beam by means of the auxiliary mirror may be carried to some intermediate degree, so that the beam may be extremely narrow in one plane, such as for instance one-half degree wide between half-power points in a plane passing through the axis of the dipole array, and moderately wide in another plane, possibly 10, 15 or 20 degrees between half-power points. Such beams are especially useful for fast high-resolution scanning for radio-echo location equipment. It can be shown that scanning with a single pencil beam involves certain limits on the combination of speed and resolution, the scanning speed permissible going down with the narrowing of the pencil beam for a given recurrence rate of signal pulses, because in practice a certain minimum target illumination for each scan appears to be necessary for satisfactory results. Maximum range requirements prevent much compensation for increased scanning speed by increased recurrence rate of signal pulses.

If a pair of beams is used, each of which is narrow in one dimension only and broad in the other cross-sectional dimension, and these beams are "crossed," which is to say that one has its narrow dimension approximately perpendicular to the narrow dimension of the other beam, and these beams are then each scanned in a direction parallel to the narrow dimension, a satisfactory high resolution and long range scan can be obtained at relatively high speed. If the area to be scanned is not unreasonably large, such as from ten degrees square to thirty or forty degrees square, the loss of gain by the fanning of the beam is not excessive, especially in view of the fact that the narrowing of the beam in one dimension increases the antenna system gain. Thus, for a high-speed high-precision locating device two systems of the type shown in Fig. 4 would be used, one mounted in the general way shown in Fig. 4 with the axis of the dipole array approximately horizontal, and the other mounted with the axis of the dipole array approximately vertical. If desired, the entire system including the two perpendicular antenna systems could be mounted so that it could be swung to scan any particular restricted solid angle. This type of apparatus is of particular importance at the very short wave lengths, such as wave lengths of several centimeters, where high resolution arrays are readily obtainable in a small space, but reliable and fast scanning methods for such high resolution apparatus have heretofore been difficult to construct.

In Fig. 4 the distributing wave guide is shown at 55 and the dipoles are located at 56. The motor 57 drives a toggle mechanism 58 to vary the orientation of the directional characteristics of the system in the same manner as was accomplished in the apparatus of Fig. 3. The dipoles 56 or, more accurately, the midline between the line of centers of the dipoles and the reflecting surface of the wave guide 55, is located at the focal axis of a semiparabolic cylinder 59. The semiparabolic cylinder 59 is a reflector, preferably made of sheet copper or aluminum, suitably supported. The wave guide 55 and the dipoles 56 are inclined upward so that the maximum illumination of the reflector occurs near the center of the semiparabolic section of the reflector instead of near the vertex, which is in this case at or near the edge. In an apparatus arranged in this manner the amount of radiation blocked off by the wave guide 55, the motor 57 and the associated apparatus for energizing, and so on, is kept to a practical minimum.

An antenna system of the type shown in Fig. 4 including a linear wave-guide-fed radiating array and an auxiliary reflector has a particular advantage in that the frequency-sensitivity with respect to the spacing between the antenna array and the auxiliary reflector is very low, if it exists at all. This is for the reason that such energy as is reflected from the auxiliary reflector back to the antenna array when the radiated beam is radiated at an oblique angle to the axis of the array will not cause the formation of standing waves in the wave guide system because the direction of the radiation so reflected back to the antenna array is such as to set up a wave travelling towards the absorber 44 (see Fig. 3) and not a wave travelling back towards the input to the antenna system. This beneficial effect does not take place when the beam is at right angles to the axis of the antenna array but, as pointed out below, when the beam is so directed there will normally be a high standing-wave ratio in the wave guide for other reasons, so that the additional difficulty is relatively immaterial.

Fig. 5 shows another form of reflector which may be used instead of the reflector 59 for concentrating the radiated beam in a plane perpendicular to the axis of the wave guide. This form of reflector may be referred to as a "cylindrical zone plate." The curved surfaces are segments of confocal cylindrical parabolas having directrix planes separated from each other by one wave length. A study of this type of reflector has shown that the directional pattern produced by means of such a reflector may be expected to be almost as desirable from the point of view of directivity as that obtained with an ordinary parabolic cylinder, but that some lowering of the gain for a given aperture is to be expected. The reflector shown in Fig. 5 is symmetrical about a plane passing through the focal axis and the lines of vertices of the various parabolic cylindrical surfaces. If desired, this type of reflector might be modified in accordance with the principles explained in connection with Fig. 4 to make it unsymmetrical with respect to this plane so that apparatus located near the focus will not substantially block off the radiation.

Fig. 6 illustrates a method of altering the

velocity of phase propagation in the distributing wave guide in order to vary the orientation of the directive pattern of the antenna system, which method may be used instead of the method shown in Fig. 2. In Fig. 6 the distributing wave guide is shown at 60. The dipoles are shown at 61, the apparatus being shown in a position such that the dipoles are below the wave guide 60, in order that the arrangements on the back side of the wave guide 60 may conveniently be shown. The end of the wave guide 60 is filled with absorbing material 62 corresponding to that shown at 44 in Fig. 3 and at 12 in Fig. 1. A series of longitudinal slots 63 is cut in the middle of the broad side of the wave guide 60 which is shown uppermost in Fig. 6, the slots preferably being made in the portions of the wave guide 60 which lie between successive dipoles 61. These slots 63, if not excessively wide, will cause substantially no interference with the normal mode of operation of the wave guide 60 because they offer practically no interruption to any current flowing in the wave guide surfaces. A plate 64 of polystyrene or other suitable dielectric material cut in such a manner as to provide tongues adapted to be inserted through the slots 63 into the wave guide 60, is mounted, by means not shown in the drawing, so that the said tongues may be reciprocated in and out of the wave guide 60 through the slots 63. In such reciprocation it is not necessary that the plate 64 be wholly withdrawn. If it is desired wholly to withdraw the plate 64 from the wave guide 60, the slot 63 might be provided with a suitable guide. Indeed the provision of a small metal sleeve on the outer side of the slotted wall of the wave guide extending around the dielectric tongue for a small distance away from the wave guide may serve to mitigate radiation from the slot in cases where the slot is wide enough to permit radiation in the absence of such sleeve.

It will be seen that the dielectric material of the plate 64 is thus introduced into portions of the wave guide 60 which have oscillating electric fields of relatively high intensity when the wave guide 60 is excited, so that the effect of the said dielectric material upon the characteristics of the wave guide will be quite marked. The said effect will be to shorten the wave length of the oscillations in the guide for a given frequency and the said wave length will be progressively shorter as the amount of dielectric material introduced into the wave guide is increased. The advantage of this method of variation of the electrical length of the wave guide 60 lies in the avoidance of discontinuities in the wave guide walls at locations of high current density. The disadvantages include the fact that the range of variation is not as wide as might be desired for some purposes and also in the fact that for certain electrical lengths the discontinuities caused by the dielectric insertion may set up reflections which are in phase and therefore additive, thus building up standing waves of considerable magnitude.

It is to be noted in this regard that for distributing wave guides of constant cross section all the dipoles will generally not be matched to the wave guide with regard to impedance relations, so that reflections will be set up on account of such mismatch. Such reflections will be at a maximum when the dipoles are ½ wave length apart (referring to the wave length in the guide) but the total reflections set up diminish as the electrical length of the guide is varied away from that corresponding to half-wave spacing, and this decrease is particularly sharp for long arrays. In general, the portion of the scanning cycle produced by varying the electrical length of the wave guide in which portion a high standing-wave ratio occurs will be limited to substantially one-half the beam-width, located symmetrically with respect to the half-wave position, which is the position at which the beam is perpendicular to the axis of the wave guide. As the array is lengthened the beam becomes sharper and the portion of the scan at which high amplitude standing waves occur becomes narrower. At the same time, however, the maximum intensity of standing waves decreases rather than increases with increase of the array length. This is due, at least in part, to the fact that for longer arrays the penetration of the coupling probe into the feed wave guide will generally be less, which results in the capacitive effect of the probes being more completely counterbalanced by the inductive effect of the holes in the wave guide wall through which the probes protrude. In addition, when the probe penetration is small and the array long, the attenuation in the feed wave guide becomes relatively more important and further prevents the building up of large standing wave amplitudes even for conditions of normal beams direction (the reflections from the more distant probes adding little because of attenuation).

It is possible to provide means to indicate the presence of a relatively high level of standing waves and such means may be used in connection with antenna systems herein described for the purpose of making an accurate indication of the time when the beam is located perpendicularly to the axis of the wave guide, thus providing a monitoring calibration for the means associated with the scanning mechanism for correlating the antenna orientation with other information obtained from received signals.

Since the regularly recurrent distribution of the dipoles in the usual case necessarily sets up considerable standing waves at the adjustment of the wave guide for 180° spacing, and since the discontinuities caused by the dielectric insertions in the wave guide in the apparatus of Fig. 6 have the same spacial periodicity of distribution, the reflection effects from both sources will have their disturbing influence for the same electrical length of the wave guide 60, so that these reflection effects do not precisely constitute an additional disadvantage of the type of arrangements shown in Fig. 6. Indeed it might be possible to cause the two reflection effects to cancel each other in part (only for some positions of the scanner, however, in the general case). In the type of apparatus shown in Fig. 6 however, it may be more difficult to keep the standing wave peaks at a reasonably low level, especially for long arrays.

The above-mentioned possibility of checking the orientation of the beam by determining the precise moment during the scanning cycle when a relatively high standing-wave ratio appears in the wave guide feeding the antenna array is of great practical significance and is applicable generally to many forms of the invention, including those of Figs. 2, 3, and 4, Fig. 7, Fig. 8, and also Fig. 1A. Apparatus for such checking purposes is indicated in a general way in Fig. 15. The standing-wave ratio measurement is adapted to give an indication of the moment when the

beam is oriented perpendicularly to the axis of the feed wave guide, which indication is independent of the effects of temperature, changes in frequency, and other effects likely to be found in practical operation. Apparatus adapted to detect standing-wave amplitudes in wave guides is well known. The information obtained from the standing-wave detector may be applied in any of a number of ways to a cathode ray tube which may also serve to present information obtained from the operation of the radio-echo location and detection system of which the wave-guide fed dipole array forms a part. Because the standing wave ratio resulting from the dipoles at different electrical lengths of the feed wave guide is governed by the same mathematical relations as the intensity of the radiation in different directions under conditions of normal beam transmission (except for a factor of 2 which comes in because the standing waves are waves which have travelled down and back in the array), the presentation of the standing wave ratio as a function of scanner position on a suitable oscilloscope, as just suggested, may serve to monitor the directional pattern of the antenna array. Damage to the antenna by way of physical deformation or the like which would cause the directional pattern to deteriorate will cause a corresponding change on the indication of the standing wave ratio.

The chief disadvantage of the suddenly increased standing-wave ratio which accompanies the production of a beam normal to the axis of the array is the possibility that the change in the load offered by the antenna resulting from the standing waves may cause the transmitting tube to shift its frequency of operation. This is of no practical consequence for standing-wave ratios of the order of magnitude encountered in arrays of 50 wave lengths or longer, so far as radio-echo detection apparatus of ordinary types is concerned, but it may have some significance in the case of specialized equipment of very high accuracy, such as equipment employed for directing anti-aircraft fire. The effect of the variation in standing-wave ratio in the neighborhood of the normal beam position of the scanner may be greatly reduced by employing means for varying the length of the wave guide between the feed wave guide of the antenna and the transmitting tube. Such means may be a section of wave guide of variable width. The electrical length of this variable portion of transmission means may then be adjusted so that the standing waves caused by the scanning of the antenna through the normal beam position have a minimum effect upon the frequency of operation of the transmitter. The variable portion of wave guide thus has the function of adjusting the electrical length of the wave guide so that the standing waves are presented to the transmitter tube in the most favorable phase. The desired adjustment for this purpose may be made readily in an experimental way with the help of suitable measuring equipment, or in some case it may be predicted theoretically.

Fig. 7 shows an improved arrangement for varying the velocity of phase propagation in the distributing wave guide (and hence the electrical length) by mechanically varying its physical width. In the arrangement of Fig. 7 the distributing wave guide 66 is defined by the space between two structures which are vertically relatively movable, the ball bearings 67 being provided to facilitate such movement. One of the said structures consists of the plate 68 and the flange structure 69, which may conveniently be soldered together, and the other of said structures consists of the plate 70 and the flange structure 71, which may likewise be soldered together. The structures 69 and 71 are provided with resonators respectively shown at 72 and 73 operating in the manner of the resonators 23, 25 and 24, 26 of Fig. 2. In order that the discontinuity in the wave guide walls should not appear at the wave guide corners, where circulating currents may be expected to be quite large, the structures 69 and 71 are cut away so that an overhanging portion, shown at 74, 75 is provided. In consequence the discontinuity in the wave guide wall is made to appear at a point nearer the center of the broad walls of the wave guide, so that the current flowing at such locations will be substantially less than the current flowing at the corner. In this manner the range of wave guide width (referring to the width of the wave guide 66) for which the resonators 72 and 73 are able to give satisfactory service is extended.

The provision of means for providing the desired relative movement of the structures 68, 69, and 70, 71 will be readily understood without further explanation. It will be seen that such means should include some arrangement for holding the two structures together, in cooperation with which the ball bearings 67 may serve as aligning means.

The practical scope of varying the directivity of an antenna array by varying the width of a wave guide feeding the elements of the said array is illustrated in Fig. 14. Fig. 14 is a diagram showing contours of equal beam angle referred to the plane perpendicular to the axis of the array, for different values of spacing between the elements of the array and for different values of the width of the feed wave guide in terms of the free-space wave length. The ratio of antenna element spacing to the free-space wave length is plotted as the ordinate, and the ratio of the width of the wave guide, sometimes referred to as a, to the free-space wave length is plotted as the abscissa. It is assumed that alternate antenna elements are provided with means for accomplishing a phase reversal as previously described.

The shaded area of the diagram indicates values of spacing and width which are unsuitable for some reason or other.

Thus wave guide widths less than 0.5λ are unsuitable because such wave guides are in the cut-off range, which is to say that they will not transmit waves of the frequency in question. Wave guide widths greater than λ are undesirable because of the likelihood of interference of the $TE_{2,0}$ mode of transmission. The other two boundaries of the useful area are determined by the appearance of additional beams corresponding to an "end fire" operation of the antenna array. Thus the line A indicates the lowest spacing and guide width required for end fire operation in one direction, which may be said to correspond to a beam of the $+\frac{3}{2}$ order, the principal beam being of the order $+\frac{1}{2}$. Likewise, the line B indicates the greatest wave guide width for which an end-fire beam will be produced in the opposite direction, which may be said to be a beam of $-\frac{1}{2}$ order.

The nomenclature just used for referring to the various orders of beams that may exist for various spacing and wave lengths relations will

be understood by reference to the formula for the angle by which the direction of maximum emitted or received radiation deviates from the normal direction to the array, which angle is referred to as θ:

$$\sin\theta=\frac{\lambda}{\lambda_g}-\frac{n\lambda}{s}$$

In this formula λ is the free space wave length, λ_g is the wave length in the feed wave guide, and s is the spacing between elements of the array. In the case of an array of non-reversed dipoles n may take the values of 0, ±1, ±2, and so on. In the case of a reversed dipole array constructed in accordance with the present invention, n is found to take the values of ±½, ±3/2 and so on. The beam which is utilized in the type of scanning normally chosen in accordance with the information shown on Fig. 14 is that for which the above equation holds when n has a value of +½.

It will be seen from Fig. 14 that the variation of the beam angle with wave guide width is not a linear relation and that the beam angle is quite sensitive to changes in wave guide width as the latter approaches the cut-off dimension (for which situation the wave length in the guide is infinite and the velocity of phase propagation is zero). Thus, for spacing between antenna elements of approximately 0.6 free-space wave lengths, a variation in beam orientation of about 25 or 30 degrees can be practically obtained. For the spacing of 0.5 free-space wave lengths and less it appears from Fig. 14 that it is not practical to include a beam normal to the axis of the array within the field of scan. For this reason a spacing of about 0.6 is usually preferred because the inclusion of the normal orientation within the scanning angle has the advantage of providing a calibration check through the occurrence of high-amplitude standing-waves for normal orientation.

If it is desired to make the angular rate of scan approximately linear a suitable cam or eccentric may be included in the mechanical motion which shifts the plate **70** with respect to the plate **63** (Fig. 7).

The cross-sectional dimensions of the feed wave guide perpendicular to the variable dimension used for scanning is not particularly critical. It should be less than half of the free-space wave length in order to prevent interference with other modes and is preferably considerably shorter than such half-wave length. About 0.3 free-space wave lengths is a convenient size. The dimensions, particularly the cross-sectional length, of the channels **72** and **73** are quite important. For relatively long guides the following dimensions have been found to be suitable, referring to the dimensions indicated by reference characters on Fig. 7.

$a=0.356\lambda$
$b=0.356\lambda$
$c=0.334\lambda$
λ=free-space wave length

One of the dipoles of the array driven by the wave guide **66** is shown in Fig. 7 at **76**. The arrangement shown in Fig. 7 for energizing the dipole **76** is a simplification of the energizing means shown in Fig. 2. In Fig. 7 the forward extension of the tubular member on which the dipole arms are mounted, which was shown in Fig. 2, has been in effect cut-off. The slots cut in the tubular member, one of which slots appears in Fig. 7 at **77** cut in the tubular member **78**, are therefore open at their outer ends and are only about an electrical quarter-wave length long. The tubular member **80** is thus supported wholly by the structure **79** which connects it electrically to the upper segment of the tubular member **78**. The rod **81** is firmly but slidably mounted in the tubular member **80** and its longitudinal position is adapted to be varied in order to adjust the degree of excitation of the dipole **76** relative to that of the other dipoles of the array. The type of dipole shown in Fig. 7 is somewhat more compact and slightly simpler in construction than the form shown in Fig. 2.

As previously indicated, the angles through which the direction of maximum effectiveness of the antenna system may be swung by varying the lateral dimension of the distributing wave guide is subject to a practical limitation which makes it advisable to limit said swing to about 30° in the forms of the invention heretofore considered, especially those of Fig. 2 and Fig. 7. Fig. 8 illustrates an arrangement of apparatus by which it is possible to double the angle through which the beam can be swung by varying the electrical length of the wave guide in any given manner. The orientation of the directive pattern of the antenna system fed by a distributing wave guide in the manner above explained depends not only upon the electrical length of the wave guide but also upon the direction of the flow of energy through the wave guide. For a given adjustment of the electrical length of the distributing wave guide at a given frequency, if when the wave guide is excited at one end the direction of maximum effectiveness of the antenna system forms an angle θ with the plane perpendicular to the axis of the distributing wave guide, when the distributing wave guide is fed from the opposite end the orientation of the said direction of maximum effectiveness will be in a direction forming an angle equal to 2θ with the previously obtained direction of maximum effectiveness and likewise at an angle of θ with the plane perpendicular to the axis of the wave guide. Consequently if the wave guide can be alternately fed from one end and then from the other and the electrical length is varied with each type of feed from an electrical length adapted to produce radiation perpendicular to the axis of the wave guide to some other electrical length, for which the direction of maximum radiation might be displaced as much as 30° from the plane perpendicular to the axis of the wave guide, the direction of maximum effectiveness of the antenna system can be made to swing first on one side of the broad side direction and then on the other. With such an arrangement it is quite practical to obtain a swing of 60°.

In Fig. 8 an arrangement is shown for exciting the wave guide **85** alternately from each end. The wave guide **85** feeds an array of dipole antennas in the general manner heretofore explained and means are provided, which are not shown in Fig. 8, for varying the electrical length of the wave guide **85** in order to vary the directional properties of the antenna system. The straight wave guide **85** which supports the antenna array is coupled at each end with a bent wave guide (shown respectively at **86** and **86***a*) leading to a reversing switch **87**. The reversing switch **87** may take any of a number of forms. It may generally be referred to as a "wave guide transposition switch."

The form of switch shown in Fig. 8 consists simply of a resonant ring pivotally mounted in a wave guide crossing. A simple crossing is formed by the wave guide **88** and **86**, **86***a*, the wave guide

88 extending beyond the crossing to an absorber 89. The switch 87 includes a resonant ring 87*a*, which is shown end-on in Fig. 8 and which is pivoted on an axis perpendicular to both wave guides (perpendicular to the plane of Fig. 8) located substantially at the center of the crossing. The resonant ring 87*a* may be round or rectangular (or it may have some other shape, or indeed a resonant structure in some other shape, which is not a ring at all, may be used), but in the rectangular wave guide system shown it is convenient to provide a resonant ring of rectangular form also. The dimensions of the ring should be such as to resonate at the frequency of operation and may be designed so to resonate in accordance with known principles. Such a resonant ring acts as a reflector of energy at such frequency. Thus when the ring 87*a* is oriented as shown in Fig. 8, communication is established for transfer of energy between the wave guide 88 and the wave guide 86 and also between the wave guide 86*a* and the absorber 89. If the resonant ring should be rotated 90°, energy-transferring relation would be established between the wave guides 88 and 86*a* and between the wave guide 86 and the absorber 89. Care should preferably be taken in operating the resonant ring 87*a* that the turning motion carries the ring through the position in which the plane of the ring is aligned with the direction of the wave guide 88 and not through the position in which the plane of the ring is at right angles to the direction of the wave guide 88. If this precaution is taken, the intermediate position of the ring 87 will couple the wave guide 88 at least in part to the absorber 89 and in consequence reflections toward the wave guide 88 will not be likely to be excessive. The motion of the resonant ring 87*a* from one position to the other may be made quite rapid by employing a suitable type of driving mechanism, such as certain magnetic types. The driving mechanism is indicated generally at 87*b*.

The absorber 89 may be simply a wave guide filled with material adapted to absorb oscillatory electric energy, corresponding in function to the absorbing material 62, or it may take other forms, such as a device constructed in accordance with the principles explained in W. W. Salisbury's patent application, Serial No. 486,608, which issued as Patent No. 2,599,944 June 10, 1952. The wave guide 88 leads directly to a transmitter 90 and leads through a branch guide 91 in which is interposed a protective electrical breakdown device 92, to a receiver 93. The apparatus required for providing the desired indication in response to received signals and for performing various synchronizing functions, with which the present invention is not directly concerned, is indicated in a general way by various rectangular enclosures.

In one position of the reversing switch 87 the transmitter will feed energy to the wave guide 86*a* which will enter the wave guide 85 at its right-hand end and proceed to the left, most of it being radiated from the various dipoles of the array and a small remaining amount proceeding down the wave guide 86, back to the switch 87 and into the absorber 89 where it is absorbed. When the transmitter is not operating and echoes of transmitted pulses energize the antennas of the array, the maximum sensitivity of the antenna array will be directed in substantially the same direction as that in which the greatest intensity of the last transmitted pulse was emitted and signals coming from such direction will excite a wave in the wave guide 85 which will flow to the right towards the receiver 93. When the switch 87 is in its other position in the wave guide 85 will be energized from the left-hand end and signals coming from the approximate direction in which the major portion of the radiated pulse was radiated will excite a wave flowing to the left in the wave guide 85 which will then proceed through the wave guide 86, the switch 87, the wave guide 88 and the wave guide 91 to the receiver 93.

For some types of apparatus an extreme range of variation of the scanning angle is not particularly desired and it is possible to devise apparatus for such purposes having a scanning range of about 10° or so, which apparatus may include certain simplifications that would be difficult to incorporate into devices for scanning over wide angles. Fig. 9 illustrates one such form of apparatus for scanning over an angle of about 10°. The form of construction shown in Fig. 9 is particularly convenient for operation at extremely short wave lengths such as 1 or 2 centimeters.

Fig. 9 shows a cross-section of a type of array embodying the principles illustrated in connection with Fig. 17 and Fig. 18. The cylindrical branch wave guides with their twisted septa are in this case fed from the narrow side of the feed wave guide (shown at 200), in order that the width of the feed wave guide 200 may be simply varied by varying the separation between the two metal pieces 201 and 202 which form the wave guide 200. No significant amount of energy will be dissipated through the gap between the pieces 201 and 202 which communicate with the wave guide 200, because this gap occurs only at the center line of each of the broad walls of the wave guide 200; across these center lines there is no tendency for oscillatory currents to flow. This method of varying the width of the wave guide 200 has the advantage that it dispenses with the necessity of providing choke resonators such as the resonators 72 and 73 of Fig. 7, but this convenient method is not believed to be practical for scanning which covers more than an angle of about 10°, because considerable amounts of energy will begin to leak out of the gap between the metal pieces 201 and 202 if this gap is made wide enough to produce the variation in width necessary for the greater range of angular scan.

As shown in Fig. 9, the cylindrical branch wave guides are formed in the same metal piece 201 which forms the upper portion of the wave guide 200. One of these branch wave guides is shown in section at 203. In order to reduce the diameter of the branch wave guide a filling of solid dielectric material such as polystyrene is provided as shown at 204. The twisted septum, which may be of thin sheet copper, is shown at 205. The bottom of the septum 205 is parallel to the axis of the wave guide 200, whereas the top of the septum 205 is perpendicular to the said axis. The septum 205 and the two pieces of solid dielectric material 204 may be assembled beforehand (if desired the dielectric material may be molded about the septum in a suitable cylindrical mold) and these assemblies may be simply inserted into the cylindrical recesses of metallic piece 201 and then aligned therein for proper orientation of the septa. As mentioned in connection with Figs. 17 and 18 in alternate elements the septa are respectively twisted in opposite directions. A small hole 206 in the wall of the wave guide 200 provides

for energy transfer from the wave guide 200 into the cylindrical branch wave guide 203. The size of the hole 206 depends upon the number of elements in the array and the desired degree of coupling.

Variation of the width of the wave guide 200 is accomplished by the motions of a rocker arm 210 controlled by the cam 211 and the cam follower 212. The rocker arm 210 is pivoted at the ball bearings 214. Since the metal piece 202 need not be very heavy and since the range of its movement for a 10° scan will not be great, the type of apparatus shown in Fig. 9 lends itself very well to rapid scanning.

Fig. 10 illustrates application of the principles of the present invention for providing an antenna system the directive maximum of which may be swung in two coordinates without motion of the radiating elements themselves. In this form of apparatus energy is introduced into a wave guide 100 at 101. This energy is transmitted from the wave guide 100 into a plurality of branch wave guides 102 which may be formed by suitable partitions in a metallic box-like structure through suitable windows 103 in one of the narrow walls of the wave guide 101. The electrical length of the wave guide 100 is adapted to be varied by movement of a lateral plunger 104. Absorbing material shown at 105 is located in the end of the wave guide 100. If desired, suitable structures having the effect of shunt susceptances may be provided in the wave guide 100 between the windows 103 in order to match out at least in part the reflections occurring in the wave guide 100 on account of the junctions effected through the windows 103.

The branch wave guides 102 are each provided with a row of dipoles in the general manner heretofore explained, the dipoles being represented in Fig. 10 in the form shown in Fig. 7. The dipoles are mounted on a single flat surface and are distributed uniformly both in the direction of the wave guide 102 and in the direction of the wave guide 100. The spacing in each of these directions should be less than the wave length in unconfined air of oscillations of the frequency intended to be transmitted or received. Accordingly, provision should be made for reversing successive arrays, either by reversing the polarity of the first dipoles in each array, or by putting reversed 90° twists in the wave guides, which may be coupled into the feed wave guide either on the narrow or wide side. The width of the wave guide 102 may conveniently be about 0.7 free space wave lengths for the oscillations in question. The electrical length of the wave guide 102 is adapted to be varied simultaneously by the movement of plates 106 of dielectric material, such as polystyrene, having tongues 107 projecting into the wave guide 102. The plates 106 are actuated in unison by the vertical motion of a plate 108 to which the plates 106 are attached. The motion of the plate 108 may be brought about by suitable shaft eccentrics or cams, or the like (not shown) or by hydraulic or other means. Motion of the plate 108 causes the orientation of the directive characteristics of the antenna system to be swung about an axis parallel to the axis of the wave guide 100 whereas motion of plunger 104 in and out of the wave guide 100 causes the said directive characteristics to be swung about an axis parallel with the axes of the wave guides 102.

Preferably one of the swinging motions is made considerably slower than the other in order that a solid angle may be scanned with relatively uniform coverage. For example, the plate 108 may be caused to move very slowly up and down while the plunger 104 operates at a higher frequency, making perhaps 20 or maybe 50 cycles of reciprocation for each cycle of the plate 108. The sharper the beam of the antenna system, the greater number of cycles it will be necessary for the plunger 104 to make for a cycle of the plate 108 in order to obtain a reasonably complete coverage of the entire solid angle in each cycle. If desired, the plate 108 and the plunger 104 may be actuated with the same periodicity but with a phase difference in their motion of one-quarter of a cycle, in which case the beam will describe a circle or more exactly a cone. Such circular motion might, if desired, be superimposed upon another motion of the beam. Circular motions of this sort are of particular utility in automatic following apparatus.

If it is desired to employ the principle illustrated in connection with Fig. 8, to extend the scanning abilities of an apparatus such as Fig. 10, the wave guides 102, instead of being terminated by absorbing masses such as the absorbing element 109, might be terminated by another wave guide parallel to the wave guide 100 and connected to the wave guide 102 by windows similar to the windows 103. In such case, it would be necessary to provide a selector switch which would enable feeding the antenna system in turn from each of the four corners through one of the extremities of the wave guide 100 or of the complimentary wave guide at the other end of the wave guide 102, the three unused extremities being connected to absorbers.

Fig. 15 illustrates another form of antenna system according to the present invention differing in minor particulars from certain forms already described. In this case the dipoles, which appear at 140, are arranged in a collinear array instead of in a broadside array. The directive pattern is still a "broadside" pattern. Phase reversing arrangements are provided in alternate dipole feeds as in previous cases. The dipole mounts 141 are of the type shown in Fig. 2. The feed wave guides constituting the dipole mounts 141 are connected with a radio transmitting and receiving system by means of a wave guide 143. The transmitter is shown at 144 and includes a vacuum tube 145 for generating high-frequency oscillations. Circuits for causing the transmitter to operate intermittently at high energy levels are included in the box shown at 146. A branch wave guide 147 leads through a protective electrical breakdown device 148 to a receiver 149, 150, which receiver includes at least one indicator 151, which may be a cathode ray tube. The circuits of the cathode ray indicator tube are coordinated with the apparatus indicated at 146 for purposes of synchronizing the indication of information obtained by the system, such synchronization being provided through suitable connections indicated by the wire 163. A wire 152, also connected to the indicator 151, is connected to a standing-wave detector apparatus 153, which may consist of a "wave separator" and a detector and which is adapted to indicate the moment of maximum standing wave ratio in the wave guide 142 for the purpose of providing a reference point on the indicator 151. Such a reference marker is a highly useful check on the operation of the system because it is independent of thermal effects on the wave guide structure, slippage in translating devices, changes in frequency of

operation and other such sources of errors. The right-hand end of the wave guide 143 is terminated with absorbing material indicated at 154.

The wave guide 143 is variable in width through a suitable arrangement which may be that of Fig. 7, or that of Fig. 2, or some other similar structure. The fixed portion of the wave guide 143 carries a flange 155 upon which a motor 156 is mounted which is arranged to drive a longitudinal shaft 157 which operates a plurality of short transverse shafts 158 which act to vary the width of the wave guide, as by the action of suitable cams located on the respective shafts 158. A translating device 160 which may be a suitable potentiometer, condenser or variable transformer ("selsyn"), is also mounted upon the fixed portion of the wave guide 143 and is adapted to be controlled by the mechanical motion of the wave guide width varying mechanism. The device 160 may be driven by a suitable cam on the shaft 157 or by a mechanical link to the movable wall of the wave guide 143, such mechanical link or cam cooperating with the electrical characteristics of the translating device to provide a suitable continuous indication of the orientation of the beam to the circuits associated with the indicator 151, through the electrical connection indicated at 161. The motor 156, the shaft 157, and apparatus associated therewith may be conveniently mounted on the opposite side of the wave guide structure 143 in such a manner that the antenna array may be used with a mirror in the form of a cylindrical parabola with a minimum of interference with the radiation pattern on the part of the scanning mechanism.

The indication of the orientation of the beam provided to the indicator 151 and its associated circuits, instead of being provided through a mechanical arrangement and translated into electrical quantities by means of a potentiometer, a variable transformer or some other type of translating device, may be provided wholly by electrical methods by providing a phase-sensitive circuit adapted to measure electrically the change in electrical length of the wave guide 143. For this purpose a pair of probes or other coupling elements associated with the wave guide 143, one near each end thereof, may be used in a suitable circuit. These probes may be placed either through the wall of the guide, to pick up the field inside, or outside the guide, to pick up the field radiated from the dipoles. Phase comparison between the two probes will indicate changes of electrical length less than a wave length and a suitable counting or registering device may be provided to indicate changes in electrical length greater than a wave length. If the dipole array is long, the latter alone may be sufficient. The counting or registering device may be associated with a reversing switch operated by the scanning mechanism so that the counting device indicates increase of electrical length during narrowing of the wave guide and decrease during broadening of the wave guide. As another possibility, a beam direction indicating system including a mechanical arrangement such as that indicated in Fig. 15, may be used for controlling the deflecting plates of the cathode ray tubes that may be the indicator 151, and electrical means of the type just mentioned may be employed to provide a series of check points or markers on the indicator 151 corresponding to electrical lengths of the wave guide 143 differing from each other by one wave length. A reduced number of check points, each of them sharply defined, can be obtained by mixing the amount of radio-frequency energy picked up by a plurality of probes spaced regularly along the array. In cooperation with the reference marker provided by the operation of the standing wave detector 153, such check points could be used to facilitate relatively accurate reading of the information presented upon the indicator 151.

Figs. 19 and 20 illustrate simple ways of providing a certain amount of concentration of the radiation of an array constructed in accordance with the present invention, with respect to direction in a plane perpendicular to the axis of the array. The concentration so provided is not very great but it is useful for many purposes. This type of arrangement is particularly effective when the dipoles are oriented to form a co-linear array since in such case all portions of the dipoles are at the same distance from the area's reflecting members. This type of reflector can, however, be utilized to some extent when the dipoles are not parallel to the axis of the feed wave guide and are therefore not co-linear.

In Fig. 19 an arrangement is shown which provides a reflector in the form of a rectangular corner or edge, one side of the rectangular corner being formed by the plate 220, which also forms the upper wall of the wave guide 218 and the other side of the corner is formed by the metal plate 221 which is mounted on the plate 220. The plate 221 is preferably mounted on the plate 220 in such a manner that the dipoles will be equidistant from both the plate 221 and the plate 220.

In Fig. 20 an arrangement is shown, the view being this time a cross-section, in which two sheet metal reflectors are mounted on the wave guide wall which carries the dipole array. These reflectors may be straight or curved and may be either symmetrically or unsymmetrically arranged with respect to the dipoles, according to the type of energy distribution which is desired. In Fig. 20 the upper reflector 225 is curved and is somewhat larger than the lower reflector 226 which is flat.

In order to provide good energy transfer characteristics between the antenna arrays using a variable-width wave guide and radio-echo transmitting and receiving equipment and in order to reduce standing waves in transmitting equipment during the operation of the latter it is desirable to provide automatically variable impedance-matching devices between the variable-width wave guide and the fixed wave guide which is connected to the radio transmitting and receiving equipment. The significance of such means arises from the fact that the characteristic impedance (or the parameter that corresponds thereto in a hollow-pipe wave guide) varies with the wave guide width for a given short dimension of the wave guide cross-section, at least if the fixed-width wave guide coupled to the variable-width wave guide is not always aligned with the center of the latter. Figs. 21 and 22 illustrate an arrangement for providing a gradual taper from the fixed wave guide to the wave guide of variable width. The taper is provided by a pivoted piece of metal 230 which forms one of the narrow sides of the end portion of the variable-width wave guide.

Fig. 21 is a front view, with the front plate 231, which carries the dipoles, partly broken away. Fig. 22 is a cross-section. The upper narrow wall 232 of the feed wave guide 233 is fixed in

position upon the front plate 231. The lower narrow wall 235 of the main portion of the wave guide 233 reciprocates uniformly in a vertical direction, as driven by the scanning mechanism, and is fastened upon a back plate 236 which partakes of the same motion. The end of the metal piece 230 which is nearest the antenna array is pivoted by means of a pin 238 at a fixed point on the back plate 236. At the other end of the metal piece 230 is provided a slot 240 which engages a pin 241 which is mounted on the fixed front plate 231. When the back plate 236 is driven by the scanning motion, therefore, the right end of the metal piece 230 will move up and down with the metal piece 235 which forms the lower wall of the main portion of the feed wave guide 233. The left-hand end of the metal piece 230, however, will be required by the pin 241 to remain in substantially the same vertical position, the mechanical motion being taken up by a certain amount of horizontal motion at the slot 240. This type of arrangement is therefore adapted to provide a tapering transition between the fixed wave guide 243 and the variable-width wave guide 233, whatever particular width the wave guide 233 may have within the range of the scanning motion.

Since the metal piece 230 moves not only relative to the fixed front plate 231 but also relative to the back plate 236 upon which it is pivoted, it is necessary to provide the metal piece 230 with two choke resonators instead of one. These are shown at 245 and 246 respectively (see Fig. 22). In order that both of these resonator grooves may be conveniently accommodated in the metal piece 230, they are filled with a solid dielectric material such as polystyrene, which results in an increase of electrical length for a given physical length, so that the physical depth dimensions can be made conveniently small.

Figs. 23 and 24 illustrate an arrangement for maintaining a desirable degree of power transfer between a wave guide of fixed width and a wave guide of variable width without the use of taper sections. This device depends upon the discovery that a satisfactory impedance match can be maintained provided that the wave guide of fixed width is moved so that it remains centered with respect to the wave guide of variable width. Fig. 23 is a back view of one form of arrangement operating on this principle and Fig. 24 is a cross-section of the same along the line 24—24 of Fig. 23.

The fixed front plate which carries the dipole is shown at 250. The movable back plate is shown at 251. A rack 252 is mounted on the latter and another rack 253 is mounted upon a bracket 254 which is carried on the front plate 250 near one of its longitudinal extremities. A pair of pinions 255 and 256 are arranged to engage the racks 252 and 253 and are mounted in a small frame 258. It will be seen that the movement of the rack 252 as a result of the scanning motion impressed upon the back plate 251 will impress upon the frame 258 a motion having half the amplitude of the driving motion. This motion is then impressed upon the fixed-width wave guide 260 by means of an arm 261 which is fastened to the wave guide 260 by means of a pivot connection.

The wave guide 260 is folded back on itself as partly shown at 262 in Fig. 23, the back portion of the part of the wave guide 260 which is so folded back being broken away at 263 in order to simplify the illustration. The general disposition of the wave guide 260 follows the arrangement of Fig. 8. At a suitable place in the portion of wave guide thus folded in back of the antenna array a wobble joint is provided in a well-known way in order to permit the wave guide 260 to follow the motion impressed upon it by the frame 258. Because the motion of the frame 258 has exactly half the amplitude of the motion of the back plate 251, the position of the frame 258 can be adjusted so that the wave guide 260 is automatically maintained centered with respect to the variable-width wave guide which feeds the antenna array.

For antenna systems in which the range of width variation of the antenna feed wave guide is relatively small, as in the case of the apparatus of Fig. 9, it is not necessary to use either an arrangement of the type of Figs. 21 and 22 or an arrangement of the type of Figs. 23 and 24. In such case the wave guide connecting to the transmitting and receiving apparatus may be simply tapered to some suitable average width and centered with respect to the average-width position of the variable-width wave guide or some other suitable mean position thereof.

Fig. 11 shows an antenna for radiating or receiving circularly polarized waves. The antenna is fed from a coaxial transmission line comprising the outer conductor 110 and the inner conductor 111. The antenna consists of two dipoles 112 and 113 which are oriented at right angles to each other. The dipole 112 is fed directly by the coaxial transmission line but the dipole 113 is fed through intervening folded portions of conductor so folded being a quarter-wave length. Consequently, the dipole 113 will be energized with a phase delay of 90° with respect to the energization of the dipole 112. The resultant radiated wave will therefore be circularly polarized.

Figs. 12 and 13 show an arrangement for utilizing antennas of the type shown in Fig. 11 in a system in accordance with the present invention. As shown in Fig. 12, in this arrangement antennas of the type shown in Fig. 11 are mounted upon a distributing wave guide 120 so as to be supported and energized by said wave guide but in a manner adapted to permit rotation of the antennas by the gears 121, 122 and 123 which are fixed to the outer conductors of the transmission lines feeding the respective antennas. Each of these gears is driven by another gear, such as those shown at 124, 125 and 126, which in turn are driven from a common source of power at suitable relative speeds. The gear ratios are so constructed that when the gears are driven by a common drive there is a progressive difference in relative rate of rotation between successive antennas for the whole length of the array. Thus the middle antenna of the array may remain fixed and the antennas on one side of the array may be arranged to rotate in one direction with the rate of rotation being such that when the antenna next to the fixed antenna rotates through an angle α the antenna next to it will rotate through an angle 2α the next one through an angle 3α and so on. The antennas on the other side of the fixed antenna will rotate in a similar manner except in the opposite direction. If desired, instead of accomplishing the rotation through a system of gearing, it could be obtained by a system of synchronous electric motors.

As will be seen from Fig. 12 alternate antennas

in the array are reversed with regard to their connection to the feed line so that when the array is in what may be termed the zero position, all the vertical dipoles will be energized in phase and all of the horizontal dipoles likewise in phase, if the spacing is 180 electrical degrees in the wave guide. The antennas are preferably separated by lengths of the wave guide 120 measuring electrically approximately 160°, although the electrical length may be varied within relatively wide limits for this purpose. An electrical spacing of 180° is to be avoided on account of the occurrence of reflections unless elaborate precautions are taken for matching the antennas to the wave guide. The general aspect of the change in the directive pattern obtained by rotating the antennas as described is the same for 160° spacing and 180° spacing but the formulae relating to the matter are simpler for the case of 180°. For 180° spacing the angle of the beam emitted by the array will be given by the formula

$$\theta=\sin^{-1}\frac{\lambda}{s}\left(\frac{\alpha}{2\pi}+k\right)$$

where k is any integer which makes θ a real angle. λ represents the wave length in free space of the radiation in question, s the spacing between antenna centers and α the angle through which the antenna next to the fixed center antenna has been rotated from the position for which the radiation was normal to the array.

The advantage of this type of system is that the beam may be swung without any oscillating motions. For certain angles, however, two beams will exist when the spacing between antennas is more than ½ of the free space wave length, but for air-filled guides of practical dimensions, a single beam is emitted for a substantial portion of the cycle. The apparatus may be turned off during other parts of the cycle. The introduction of solid dielectric material into the wave guide 120 may permit increase of the angle through which the beam can be swung without the occurrence of ambiguity.

A special type of auxiliary reflector is necessary for practical application of an apparatus of the type illustrated in Fig. 12. An apparatus of the type shown in Fig. 12 is not suitable for sending out pulses of energy and receiving them at the same time in the normal way because the returning waves, having been reflected once, will in effect be circularly polarized in the opposite sense and the components thereof will be cancelled in the antenna elements instead of being reinforced, so that no waves will be produced in the wave guide 120. Thus the antenna system could not be used for receiving and transmitting in an ordinary duplex-operation system, except for the reception of echoes from double reflections. Antenna systems of this type can, however, be used in ordinary duplex-operation systems by providing a special type of auxiliary reflector as shown in Fig. 12. The auxiliary reflector shown in Fig. 13 has the shape of a semi-parabolic cylinder and consists of a reflecting metallic sheet 130, a dielectric material on the front of the reflecting sheet 130 having a thickness of approximately ⅛ wave length and shown at 131, and a series of parallel wires parallel to the focal axis of the parabolic cylinder 130 mounted on the front face of the dielectric material 131. These parallel wires are indicated at 132.

Circularly polarized waves are radiated by an array of antennas one of which is shown at 135, which antennas are fed by the wave guide 136 and are rotated by the spur gears 137 and 138 and by the bevel gears 139 and 139a. The bevel gear 139a is mounted on a drive shaft which provides a common drive for all the rotating antennas. When the circularly polarized radiation reaches the parallel wires 132, the horizontal component is reflected but the vertical component proceeds through the dielectric material 131 to the sheet 130 where it in turn is reflected and proceeds back through the dielectric material. Since the dielectric material has a thickness of ⅛ wave length, the additional path of the vertical component has an electrical length of a quarter-wave length, so that the resultant of the reflected vertical component and the horizontal component reflected by the wires 132 will be a plane-polarized wave, the plane of polarization being at an angle of 45° to the horizontal. When echoes of the same polarization are received, the auxiliary reflector 130, 131, 132 will convert the received wave into circular polarization which is adapted to be picked up by the antennas 135 and to set up a wave in the wave guide 136 and this wave will travel toward the transmitter. Such wave is then transmitted to a branch wave guide (not shown) leading to a receiver (not shown). The antennas 135 and the wave guide 136 are so located that the focal axis passes between the antennas and the nearer side of the wave guide 136, so that the reflector 130, 131, 132 will act to concentrate the beam of radiation produced.

For large deviations of the radiated beam from the plane normal to the axis of the wave guide 136, the phase change of the vertical component of the radiation in the dielectric material 131 will be less than the desired 90°, so that the apparatus will function less effectively. This effect will be less noticeable, the higher the dielectric constant of the dielectric material used, because of refraction of the ray from air into the dielectric medium. The phase change is reduced approximately by the factor cos θ_2, when θ_2, the angle of refraction, is small. It is precisely for the greater deviations, however, that there arises the difficulty mentioned in connection with Fig. 12 relating to the formation of more than one beam. Thus another reason exists in the apparatus of Fig. 13 for shutting off the transmitter for the period during which the position of the rotatable antennas is such that the radiated beam would have an orientation at a large angle to the plane normal to the axis of the wave guide 136.

Another advantage of the apparatus shown in Figs. 12 and 13 is that the standing-wave ratio in the wave guide 136 could be expected to remain substantially constant since the rotation of the antennas should have practically no effect upon the impedance match between the antennas and the wave guide 136.

Although the apparatus shown in Figs. 12 and 13 uses a distributing wave guide of fixed dimensions and electrical length, the means for rotating the various antennas constitute in effect means for causing a progressive relative shift in phase between successive antennas of the array, just as the means illustrated in connection with other forms of the invention for varying the velocity of phase propagation in and the electrical length of the distributing wave guide likewise acted as means for producing a controllable amount of a progressive relative shift in phase between successive elements of the antenna array.

What is claimed is:

1. An antenna system with a variable directional characteristic including a plurality of uniformly spaced dipoles, successive dipoles being separated by not more than the free-space wave length of waves in connection with which said system is adapted to operate, a wave guide in energy-transferring relationship with said dipoles, means for varying the phase velocity in at least portions of said wave guide, and means providing for a 180° phase shift of radiation from alternate dipoles in addition to such phase shift as arises from said wave guide.

2. An antenna system with a variable directional characteristic including a plurality of regularly spaced dipoles separated by not more than the free-space wave length of oscillations in connection with which said system is adapted to operate, a hollow, metallic wave guide in energy-transferring relation with said dipoles, means for connecting said dipoles with said wave guide to complete said energy transferring relation providing for reversed connections for alternate dipoles, and means for varying the electrical length of at least portions said wave guide.

3. An antenna system with a variable directional characteristic including a row of uniformly spaced dipoles separated by not more than free-space wave length of oscillations for which the said system is adapted, a hollow, metallic wave guide, means coupling each of said dipoles in electrical energy-transferring relation with said wave guide, said means all having substantially the same electrical length but providing reversed connections and consequent phase inversion for alternately located dipoles, and means for varying in the same proportion the electrical length of the respective portions of said wave guide lying between said dipole-connecting means.

4. An antenna system with a variable directional characteristic including a row of uniformly spaced dipoles arranged with their centers substantially in a straight line and separated by less than the free-space wave length of oscillations for which the said system is adapted, a straight, hollow, metallic wave guide, means coupling each of said dipoles to said wave guide in electrical energy-transferring relation, and means all having substantially the same electrical length but providing reversed connections and consequent phase inversion for alternate dipoles of said row, and means disposed within said wave guide for varying the phase velocity in at least portions of said wave guide adapted to vary in the same proportion the electrical length of the respective portions of said wave guide lying between said dipole-connecting means.

5. An antenna system with a variable directional characteristic including a row of dipoles separated by not more than the free-space wave length of oscillations for which the said system is adapted, a hollow wave guide adapted to transmit electromagnetic energy in the $TE_{0,1}$ mode without substantial interference from other modes, means associated with each of said dipoles coupling said dipoles to said wave guide in electrical energy transferring relation, said means all having substantially the same electrical length but providing reversed connections and consequent phase inversion for alternately located dipoles, and means for varying in the same proportion the electrical length of respective portions of said wave guide lying between said dipole-connecting means.

6. An antenna system according to claim 2 having also means for independently adjusting the coupling between the respective dipoles and the wave guide in energy transferring relation therewith.

7. An antenna system with a variable directional characteristic including a straight hollow wave guide, a row of uniformly spaced dipoles supported on said wave guide, successive members of said row having their respective centers separated by less than the free-space wave lengths of oscillations for which the said system is adapted, supporting and connecting means for each of said dipoles for supporting said dipoles with respect to said wave guide and connecting them therewith in electrical energy transferring relation, said means all having substantially the same electrical length but those of said means which are associated with alternate dipoles of said row having reversed connections with said dipoles adapted to produce phase inversion, and means disposed within said wave guide for varying in the same proportion the electrical length of the respective portions of said wave guide lying between successive supporting and connecting means.

8. An antenna system according to claim 7 in which the supporting and connecting means associated with the dipoles include a central conductor projecting into said wave guide which is adjustable in respect of the extent it projects therein.

9. An antenna system in accordance with claim 2 in which the wave guide therein specified is terminated at one extremity by means absorbent of electrical oscillations from said wave guide without the production of substantial reflection.

10. An antenna system including a row of dipoles mounted on a wave guide at a distance of approximately a quarter-wave length from the outer surface thereof and connected electrically to said wave guide by means of connecting means, the connections of which are reversed in the case of alternate dipoles of said row, the centers of said dipoles being spaced by less than the free-space wave length of oscillations for which said antenna system is adapted, means for varying the electrical length of said wave guide, a reflector having the shape of a portion of a parabolic cylinder located with its focal axis parallel to the axis of said wave guide and lying between said wave guide and said row of dipoles, said reflector being further oriented so that the direction of maximum radiation of said dipoles in a plane perpendicular to the axis of said wave guide is directed approximately toward the central part of the intersection of such plane with the said reflector.

11. An antenna system according to claim 3 in which the means for varying the electrical length of portions of said wave guide comprises tongues of dielectric material protruding through centrally located longitudinal slots in a wall of said wave guide and into said wave guide together with means for simultaneously reciprocably moving said tongues of dielectric material in said slots.

12. An antenna system including a substantially rectangular wave guide of variable width formed of two laterally shiftable portions, said portions each including a plate and a flange structure, said flange structure being shaped to include a corner of the said wave guide and being further provided with a groove adapted to cooperate with clearance between the said por-

tions to produce a relatively low impedance between the said portions at the wave guide boundary, a row of tubular structures supported on one of said portions and projecting outwardly from said wave guide, each of said structures supporting a dipole in electrical energy-transferring relation with said wave guide, said structures being spaced from each other at a distance less than the free-space wave length of oscillations for which said antenna system is adapted, and means for actuating said laterally shiftable portions of said wave guide to vary the width of said wave guide.

13. An antenna system with a variable directional characteristic including a relatively straight, hollow, rectangular wave guide, a row of dipoles mounted on said wave guide and arranged to be excited by said wave guide with a constant phase difference between successive dipoles, said dipoles being spaced between centers by less than the free-space wave length of oscillations for which this said antenna system is adapted, means for varying the electrical length of said wave guide, additional wave guides connecting the respective ends of said first-mentioned wave guide to a wave guide reversing switch, a wave guide reversing-switch connecting to said additional wave guides, to an energy absorber, and to a wave guide associated with a radio apparatus, and adapted to connect said apparatus alternately to either of said additional wave guides and simultaneously to connect said absorber to the other of said additional wave guides, and means for operating said reversing switch intermittently to provide for operation of said electrical-length-varying means while the said reversing switch is in each of its positions.

14. An antenna system having a variable directional characteristic including a substantially straight wave guide, a plurality of antenna elements electrically connected to said wave guide and physically mounted thereon and adapted to radiate circularly polarized waves when excited by said wave guide, said antenna elements being spaced at intervals of less than the free-space wave length of oscillations for which the said antenna system is adapted, alternately located antenna elements among the said antenna elements being reversely connected to said wave guide, means for rotating all but one of said antenna elements at proportional but different rates of rotation such that for all positions of such means said antenna elements will be oriented either so as to radiate energy from said wave guide in phase or so as to radiate energy with a progressive constant change of phase between successive antenna elements.

15. An antenna system having a variable directional characteristic including a substantially straight wave guide, a plurality of antenna elements electrically connected to said wave guide and physically mounted thereon and adapted to radiate circularly polarized waves when excited by said wave guide, said antenna elements being spaced at intervals of less than the free-space wave length of oscillation for which the said antenna system is adapted, alternately located antenna elements among the said antenna elements being reversely connected to said wave guide, means for providing rotation of each said antenna elements relative to each of the other said antenna elements, means for providing relative rotation such that for all positions of such means said antenna elements will be oriented so as to radiate energy from said wave guide with a substantially constant difference in their respective phases, which difference may be zero, said phase difference being progressive longitudinally of the array of said elements.

16. An antenna system with a variable directional characteristic including a plurality of uniformly spaced antenna elements, a straight, hollow wave guide arranged to transfer electrical oscillatory energy to and from said antenna elements, means associated with said wave guide for producing a progressive change of phase in radiation from said antenna elements when said antenna elements are energized from a common source, means for varying the degree of said progressive change of phase, a wave guide transposition switch adapted to connect the members of one pair of wave guides respectively to the members of another pair of wave guides alternately in direct or reversed relationship, an absorber apparatus, two connecting wave guides connected respectively to each end of said straight wave guide and also connected respectively to said switch as one of said pairs of wave guides, a wave guide connection to said absorber apparatus and a wave guide connection to transmitting and receiving apparatus both connected to said switch as the other of said pairs of wave guides.

17. An antenna system with a variable directional characteristic including a plurality of uniformly spaced antenna elements, a substantially straight, hollow wave guide arranged to transfer electrical oscillatory energy to and from said antenna elements, means disposed within said wave guide arranged to produce a progressive change of phase in radiation from said antenna elements when said antenna elements are energized from a common source, means for varying the degree of said progressive change of phase, a wave guide transposition switch arranged to connect the members of one pair of wave guides respectively to the members of another pair of wave guides alternately in direct or reverse relationship, two connecting wave guides connected respectively to each end of said straight wave guide and also connected respectively to said switch as one of said pairs of wave guides, a wave guide connection to an absorber apparatus and a wave guide connection to a transmitting and receiving apparatus both connected to said switch as the other of said pairs of wave guides, means arranged to provide repeated operation of said switch in coordination with the operation of said means adapted to produce a progressive change of phase, and means operatively coupled with last-mentioned means and with said means for operating said switch for providing information to the receiving portion of said transmitting and receiving apparatus for the purpose of providing indication of the orientation of the sensitivity maximum of the said variable directional characteristic when a signal is received through said antenna system.

18. An antenna system with a variable directional characteristic including a row of uniformly spaced dipoles separated by not more than the free-space wave length of oscillations for which the said system is adapted, a straight, hollow wave guide arranged to transfer electric oscillatory energy to and from said dipoles, each of said dipoles having means for coupling said dipoles to said wave guide in electrical energy-transferring relation, said means all having substantially the same electrical length but providing reversed connections and consequent phase-inversion for alternately located dipoles, means within said

guide for varying in the same proportion the electrical length of the respective portions of said wave guides lying between said dipole-coupling means, a wave guide transposition switch arranged to connect the members of one pair of wave guides respectively to the members of another pair of wave guides alternately in direct or reversed relationship, an absorber apparatus, two connecting wave guides connected respectively to each end of said straight wave guide and also connected respectively to said switch as one of said pairs of wave guides, a wave guide connection to said absorber apparatus and wave guide connection to a transmitting and receiving apparatus, both being connected to said switch as the other of said pairs of wave guides, and means for coordinating the operation of said switch with said means for varying the electrical length of portions of said straight wave guide.

19. An antenna system with a variable directional characteristic including a plurality of uniformly spaced antenna elements, successive antenna elements being separated by not more than the free-space wave length of waves in connection with which said system is adapted to operate, a substantially straight, hollow, rectangular wave guide in energy-transferring relationship with said antenna elements, means for varying the electrical length of said wave guide including means adapted to vary the broader cross-sectional dimension of said wave guide, said wave guide and said means being constituted by structures relatively laterally shiftable and equipped with grooves dimensioned to function as choke resonators for the preservation of substantial effective electrical continuity of the walls of said wave guide at radio frequencies of operation in spite of the construction of said wave guide in laterally shiftable portions, and means providing for a 180° phase shift of radiation from alternate antenna elements in addition to such phase shift as arises from lateral shifting of said structures.

20. An antenna system with a variable directional characteristic including a row of uniformly spaced dipoles separated by not more than the free-space wave length of oscillations for which the said system is adapted, a substantially straight, rectangular, hollow wave guide, means coupling each of said dipoles with said wave guide in electrical energy-transferring relation, said means all having substantially the same electrical length but providing reversed connections and consequent phase-inversion for alternately located dipoles, and means for substantially uniformly varying the width of said wave guide within the dimensional range suitable for transmission of energy therein in only the $TE_{0,1}$ mode, said means and said wave guide being constituted by at least two relatively laterally shiftable structures provided with longitudinal modifications of their surfaces to form choke resonators for preserving substantial effective continuity at radio frequencies of operation for the walls of said wave guide in spite of the construction thereof in the form of laterally shiftable structures.

21. An antenna system with a variable directional characteristic including a plurality of uniformly spaced antenna elements, successive antenna elements being separated by not more than the free-space wave lengths of waves in connection with which said system is adapted to operate, a straight hollow, rectangular wave guide in energy-transferring relationship with said antenna elements, means for providing a 180° phase shift in radiation from alternate antenna elements in addition to such phase shift as arises from said wave guide, means for varying the width of said wave guide within the dimensional range suitable for exclusive transmission of the $TE_{0,1}$ mode of oscillation, said wave guide and said means being constituted by two structures laterally shiftable relative to each other, said means for varying the width of said wave guide including a driving linkage adapted to vary the width of said wave guide relatively slowly towards the narrow end of the range of variation of said wave guide width and relatively rapidly towards the wide end of said range of variation.

22. Apparatus in accordance with claim 21 in which said driving linkage includes a plurality of toggles distributed along the length of said straight wave guide.

23. In radio location equipment, an antenna system with a variable directional characteristic including a plurality of uniformly spaced antenna elements, successive antenna elements being separated by not more than the free-space wave length of waves in connection with which said system is adapted to operate, a substantially straight wave guide in energy-transferring relationship with said antenna elements, means providing for a 180° phase shift of radiation from alternate antenna elements in addition to such phase shift as arises from said wave guide, and including also means for varying in the same proportion the electrical length of the respective portions of said wave guide lying between said antenna elements, means cooperating with said antenna system responsive to energy internally reflected in said antenna system during the time said antenna system is radiating, which means is adapted to detect said energy and to provide a signal indicating intensity of said energy, and means including a cathode ray tube for displaying the variation of the intensity of said energy in accordance with the operation of the said means for varying the electrical length in said wave guide and thereby to provide information concerning the directional radiation pattern of said antenna system.

24. In radio location equipment, an antenna system with a variable directional characteristic including a plurality of uniformly spaced dipoles, successive dipoles being separated by not more than the free-space wave length of waves in connection with which said system is adapted to operate, a substantially straight, hollow wave guide in energy-transferring relationship with said dipoles, means providing for 180° phase shift of radiation from alternate dipoles in addition to such phase shift as arises from said wave guide, means for varying in the same proportion the electrical length of the respective portions of said wave guide lying between said dipoles, and means including a plurality of pick-up devices associated with said wave guide and distributed along its length for comparing the phase of waves in said wave guides at the respective locations of said pick-up devices, said last-mentioned means being arranged to produce a plurality of markers corresponding to predetermined electrical lengths of said wave guide, and presenting said markers upon a cathode ray tube indicator to provide information concerning the direction of the radiation pattern of said system.

25. An antenna system including a straight rectangular hollow wave guide, a plurality of uniformly spaced branch transmission means of substantially equal electrical length mounted on said wave guide and electrically coupled to the

interior of said wave guide, a plurality of antenna elements respectively mounted on said transmission means, successive elements being separated by not more than the free-space wave length of waves in connection with which said antenna system is adapted to operate, said antenna elements being dipoles oriented parallel to each other and mounted on said transmission means at a distance from a wall of said wave guide equal to a small odd number of quarter-wave lengths, said antenna elements and said transmission means being so arranged as to provide an additional 180° phase shift of radiation from alternate antenna elements in addition to such phase shift as arises from said wave guide, and a reflecting surface mounted on said wall of said wave guide for concentrating the radiation from said antenna system with respect to directions lying in a plane normal to the axis of said antenna system.

26. An antenna system having a variable directional characteristic including a section of hollow rectangular wave guide, a plurality of antenna elements mounted on a broad wall of said guide and constructed to radiate circularly polarized waves when excited by said wave guide, alternately located antenna elements being reversely electrically connected to said wave guide, and means for rotating said antenna elements at proportional but different rates of rotation to vary the phase of radiation between successive elements in a predetermined manner.

27. An antenna system having a variable directional characteristic including a section of hollow rectangular wave guide, a plurality of antenna elements electrically coupled to said wave guide and adapted to radiate circularly polarized waves when excited by said wave guide, means for providing relative rotation of said antenna elements such that for all positions of said means said elements will be oriented so as to radiate energy from said wave guide with a substantially constant difference in their respective phases, said phase difference being progressive longitudinally of the array of said elements.

28. An antenna system with a variable directivity characteristic including a straight, hollow, rectangular wave guide having means for varying the broad cross-sectional dimension thereof, said means including a slidable plunger forming one wall of said wave guide, said plunger being provided with clearances and grooves adapted to provide low radio frequency impedance across the corners of the wave guide, the position of which is defined by the position of said plunger, a series of tubular structures projecting outwardly on one of the walls of said wave guide, dipoles mounted on each of said structures for energy transfer between said dipoles and said wave guide, said structures each having a central conductor cooperating therewith for electrical coupling between said dipoles and said wave guide, said structures being distributed along the length of said wave guide with a spacing between centers less than the free-space wave length of oscillations for which said system is adapted, and means for actuating said plunger for cyclically varying the electrical length of said wave guide.

29. An antenna system with a variable directivity characteristic including a straight, hollow, rectangular wave guide having means for varying the broad cross-sectional dimension thereof, said means including a slidable plunger forming one wall of said wave guide, said plunger being provided with clearances and grooves adapted to provide low radio frequency impedance across the corners of the wave guide, the position of which is defined by the position of said plunger, a row of uniformly spaced dipoles separated by not more than the free-space wave length of oscillations for which said system is adapted, means coupling each of said dipoles in electrical, energy-transferring relation with said wave guide, said coupling means providing reversed connections and consequent phase inversion for alternately located dipoles, and means for actuating said plunger for cyclically varying the electrical length of said wave guide.

30. An antenna system with a variable directivity characteristic including a straight, hollow, rectangular wave guide having means for varying the broad cross-sectional dimension thereof, said means including a slidable plunger forming one wall of said wave guide, said plunger being provided with clearances and grooves adapted to provide low radio frequency impedance across the corners of the wave guide, the position of which is defined by the position of said plunger, a row of uniformly spaced dipoles separated by not more than the free-space wave length of oscillations for which said system is adapted, means coupling each of said dipoles in energy-transferring relation with said wave guide, said coupling means providing reversed connections and consequent phase inversion for alternately located dipoles, and means for actuating said plunger including a plurality of toggle links pivotally secured to said plunger, a common driving rod arranged to drive said toggle links, and an eccentric drive associated with said driving rod for imparting a reciprocating motion thereto.

31. An antenna system comprising, in combination, a section of hollow, rectangular wave guide, a row of dipoles mounted on said wave guide and electrically coupled to said wave guide by connecting means, the connections of which are reversed between alternate dipoles of said row, the centers of said dipoles being spaced by less than the free-space wave length of oscillations for which said antenna system is adapted, means for varying the electrical length of said wave guide, and a reflector having the shape of a portion of a parabolic cylinder coextensive with said section of wave guide and located with its focal axis parallel to the axis of said wave guide and lying between said wave guide and said row of dipoles, said reflector being further oriented so that the maximum radiation of said dipoles in a plane perpendicular to the axis of said wave guide is directed approximately toward the central part of the intersection of such plane with said reflector.

32. An antenna system comprising, in combination, a section of hollow, rectangular wave guide, a row of dipoles mounted on said wave guide in energy-transferring relation therewith, alternate dipoles being reversely connected to said wave guide, the centers of said dipoles being spaced by less than the free-space wave length of oscillations for which said antenna system is adapted, means for varying the electrical length of said wave guide, and a stationary reflector having the shape of a portion of a parabolic cylinder located with its focal axis parallel to the axis of said wave guide and lying between said wave guide and said row of dipoles.

33. An antenna system comprising, a section of hollow, rectangular wave guide, a row of uniformly spaced dipoles separated by not more than the free-space wave length of oscillations for

which said system is adapted mounted on a wall of said wave guide, means coupling each of said dipoles in electrical energy-transferring relation with said wave guide, said means providing reversed connections and consequent phase inversion for alternately located dipoles, and means for varying the electrical length of said wave guide comprising tongues of dielectric material protruding through centrally located, longitudinal slots in a wall of said wave guide together with means for simultaneously reciprocably moving said tongues of dielectric material in said slots.

34. An antenna system comprising, a section of hollow, rectangular wave guide, a row of uniformly spaced dipoles separated by not more than the free-space wave length of oscillations for which said system is adapted mounted on one broad wall of said wave guide, means coupling each of said dipoles to said wave guide in energy-transferring relationship, and means for varying the electrical length of said wave guide comprising tongues of dielectric material protruding through longitudinal slots in the other broad wall of said wave guide and spaced between said dipoles together with means for simultaneously reciprocally moving said tongues of dielectric material in said slots.

35. An antenna system comprising, a section of hollow, rectangular wave guide, a row of dipoles uniformly spaced longitudinally on a broad wall of said wave guide, and means for varying the electrical length of said wave guide comprising tongues of dielectric material protruding through longitudinal slots in the other broad wall of said wave guide together with means for simultaneously reciprocally moving said tongues of dielectric material in said slots.

36. An antenna with a variable directivity characteristic comprising, a substantially rectangular wave guide of variable width formed of two laterally shiftable portions, said portions each including plate and flange structures, said flange structures being shaped to include a corner of the said wave guide and being further provided with a groove adapted to cooperate with clearance between the said portions to produce a relatively low impedance between the said portions at the wave guide boundary, a row of antenna elements mounted on one of said plates and electrically coupled to said wave guide, and means for actuating said laterally shiftable portions of said wave guide to vary the width of said wave guide.

37. An antenna with a variable directivity characteristic comprising a rectangular wave guide formed of two laterally shiftable portions, said portions each including a plate and flange structure, said flange structures being formed to provide a relatively low impedance between said portions at the wave guide boundary, a row of antenna elements mounted on one of said plates and electrically coupled to said wave guide, and means for varying the electrical length of said wave guide comprising means for actuating said laterally shiftable portions to vary the width of said wave guide.

38. An antenna system with a variable directional characteristic including a first section of hollow, rectangular wave guide, a row of dipoles mounted on said wave guide and electrically coupled thereto, means for varying the electrical length of said section of wave guide, a wave guide reversing switch, additional rectangular wave guides connecting the ends of said first section

of wave guide to said wave guide reversing switch, said switch also connecting said wave guides to an energy absorber and to a wave guide coupled with radio apparatus and being adapted to connect said apparatus alternately to either of said additional wave guides and simultaneously to connect said absorber to the other of said additional wave guides, and means for operating said reversing switch intermittently to provide for operation of said electrical length-varying means while the said reversing switch is in each of its positions.

39. An antenna system including a section of hollow, rectangular wave guide having a plurality of slots in a narrow wall thereof uniformly spaced longitudinally of said section, said slots being spaced between centers by less than the free-space wave length of energy for which said system is adapted, and plates of dielectric material secured to said narrow wall and covering alternate ones of said slots, said dielectric material having a high dielectric constant and said plates having a thickness adapted to produce approximately 180° phase shift of said energy with respect to the phase which said oscillations would have in the absence of said plates.

40. An antenna system comprising, in combination, a section of hollow, rectangular wave guide, a plurality of antenna elements mounted on a broad wall of said guide and constructed to radiate circularly polarized waves when excited by said wave guide, means for rotating said antenna elements at proportional but different rates of rotation to vary the phase of radiation between successive elements in a predetermined manner, and a compound reflector having the shape of a portion of a parabolic cylinder located with its focal axis oriented parallel to the axis of said wave guide, said reflector comprising a back surface of metallic material adapted to reflect waves polarized such that the electric vector lies in a plane perpendicular to the axis of said wave guide, an intermediate layer of dielectric material having an electrical thickness of substantially one-eighth wave length and a front surface consisting of parallel conductors parallel to the axis of said wave guide and adapted to reflect waves polarized such that the electric vector lies substantially in a plane passing through the axis of said wave guide.

41. An antenna system comprising, in combination, a section of hollow, rectangular wave guide, a plurality of antenna elements electrically coupled to said wave guide and adapted to radiate circularly polarized waves when excited by said wave guide, means for providing relative rotation of said antenna elements such that for all positions of said means said elements will be oriented so as to radiate energy from said wave guide with a substantially constant difference in their respective phases, said phase difference being progressive longitudinally of the array of said elements, and a compound reflector having the shape of a portion of a parabolic cylinder located with its focal axis oriented parallel to the axis of said wave guide, said reflector being constructed to introduce a 90° phase shift of vertically polarized waves relative to the phase of horizontally polarized waves to produce a resultant radiation having plane polarization.

42. An antenna system comprising, in combination, a section of hollow, rectangular wave guide, a plurality of antenna elements electrically coupled to said wave guide and adapted to radiate circularly polarized waves when excited

by said wave guide, means for providing relative rotation of said antenna elements such that for all positions of said means said elements will be oriented so as to radiate energy from said wave guide with a substantially constant difference in their respective phases, said phase difference being progressive longitudinally of the array of said elements, and a compound reflector having the shape of a portion of a parabolic cylinder located with its focal axis oriented parallel to the axis of said wave guide and arranged to be illuminated by radiation from said antenna elements, said reflector comprising a back surface of metallic material, an intermediate layer of dielectric material having an electrical thickness of substantially one-eighth wave length at the frequency of operation and a front surface consisting of parallel conductors oriented parallel to the axis of said wave guide.

43. An antenna system comprising, in combination, a section of hollow, rectangular wave guide, a plurality of antenna elements electrically coupled to said wave guide and adapted to radiate circularly polarized waves when excited by said wave guide, means for providing relative rotation of said antenna elements such that for all positions of said means said elements will be oriented so as to radiate energy from said wave guide with a substantially constant difference in their respective phases, said phase difference being progressive longitudinally of the array of said elements, and a compound reflector having the shape of a portion of a parabolic cylinder located with its focal axis oriented parallel to the axis of said wave guide and between said wave guide and said antenna elements, said reflector comprising a back surface of metallic material adapted to reflect waves polarized to have electric vectors perpendicular to the axis of said wave guide, an intermediate layer of dielectric material having an electrical thickness of substantially one-eighth wave length at the frequency of operation, and a front surface consisting of a plurality of parallel conductors parallel to the axis of said wave guide adapted to reflect waves polarized to have electric vectors which lie substantially parallel to the axis of said wave guide.

44. An antenna system comprising, in combination, a plurality of uniformly spaced dipoles spaced apart by not more than the free-space wave length of waves at the frequency of operation, a section of rectangular wave guide in energy-transferring relationship with said dipoles, means providing for a 180° phase shift of radiation from alternate dipoles in addition to such shifts as arise from said wave guide, means for varying in the same proportion the electrical length of the respective portions of said wave guide lying between said dipoles, and means for continuously measuring the electrical length of said wave guide including means for comparing the phase of waves in said guide at at least two longitudinally spaced locations in said wave guide, a counting device adapted to register the number of complete cycles of phase change detected by said phase-comparing means, and a reversing means associated with said counting device and said means for varying the electrical length of said wave guide arranged to determine whether said counting device is adapted to add or to subtract in accordance with whether the electrical length is being lengthened or being shortened.

45. An antenna system comprising, in combination, a section of straight, hollow, rectangular wave guide, a plurality of uniformly spaced dipoles mounted on a wall of said wave guide and electrically coupled thereto, means for varying the electrical length of said wave guide, and means for continuously measuring the electrical length of said wave guide including means for comparison of the phase of waves in said wave guide at at least two longitudinally spaced locations in said wave guide, a counting device adapted to register the number of complete cycles of phase change detected by said phase-comparing means, and reversing means associated with said counting device and with said means for varying the electrical length of said wave guide adapted to determine whether said counting device is adapted to add or to subtract, in accordance with whether the electrical length of said guide is respectively being lengthened or being shortened.

46. An antenna system with a variable, directional characteristic comprising, a section of hollow, rectangular wave guide, a plurality of uniformly spaced dipoles mounted on a wall of said guide and electrically coupled thereto, means for varying the electrical length of said wave guide, means coupled to said wave guide for detecting energy internally reflected in said wave guide and providing a signal indicative of the intensity of said energy, and means including a cathode ray tube for displaying the variation of the said energy in accordance with the operation of said means for varying the electrical length of said wave guide thereby to provide information concerning the direction of the radiation pattern of said antenna system.

47. An antenna system with a variable directional characteristic including a straight rectangular hollow wave guide having means for varying the broad cross-sectional dimension thereof, said means including a slidable plunger forming one wall of said wave guide, said plunger being provided with clearances and grooves adapted to provide low radio frequency impedance across the corners of the wave guide, the position of which is defined by the position of the said plunger, a series of tubular structures projecting outwardly on one of the walls of said wave guide, dipoles mounted on each of said structures in a manner providing for energy transfer between said dipoles and said wave guide, said structures each having a central conductor cooperating therewith for electrical coupling between said dipoles and said wave guide, said structures being distributed along the length of said wave guide with a spacing between centers less than the free space wave length of oscillations for which the said system is adapted, and means for actuating said plunger for varying the electrical length of said wave guide.

48. An antenna system with a variable directional characteristic including a straight rectangular hollow wave guide having means for varying the broad cross-sectional dimension thereof, said means including a slidable plunger forming one wall of said wave guide, a series of tubular structures projecting outwardly on one of the walls of said wave guide, dipoles mounted on each of said structures in a manner providing for energy transfer between said dipoles and said wave guide, said structures each having a central conductor cooperating therewith for electrical coupling between said dipoles and said wave guide, said structures being distributed along the length of said wave guide with a spacing between centers less than the free space wave length of

oscillations for which the said system is adapted, and means for actuating said plunger for varying the electrical length of said wave guide, which actuating means include a plurality of toggle links, a common driving rod, and an eccentric drive associated with said driving rod for imparting a reciprocating motion thereto.

LUIS W. ALVAREZ.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,708,515	Meissner	Apr. 9, 1929
2,130,675	Peterson	Sept. 20, 1938
2,206,923	Southworth	July 9, 1940
2,283,620	Alford	May 19, 1942
2,283,935	King	May 26, 1942
2,304,015	Peterson	Dec. 1, 1942
2,408,435	Mason	Oct. 1, 1946
2,412,320	Carter	Dec. 10, 1946
2,432,990	Hansen	Dec. 23, 1947
2,433,368	Johnson	Dec. 30, 1947
2,436,830	Sharpless	Mar. 2, 1948
2,461,005	Southworth	Feb. 8, 1949
2,462,881	Marchetti	Mar. 1, 1949
2,464,276	Varian	Mar. 15, 1949

FOREIGN PATENTS

Number	Country	Date
23,155/35	Australia	June 22, 1936

OTHER REFERENCES

Electronics, March 1943, page 76.