SLOTTED-WAVEGUIDE ANTENNA WITH MOVEABLE WAVEGUIDE RIDGE FOR SCANNING

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ABSTRACT OF THE DISCLOSURE

A waveguide antenna having longitudinal slot formed therein for radiating a fan-shaped beam of energy. A longitudinal ridge element is transversely movable and insertable into and out of the waveguide to selectively increase and decrease the energy propagation velocity from the characteristic nominal velocity of the waveguide whereby the fan-shaped beam is swept in either direction from a neutral position generally normal to the waveguide axis.

This is a division of co-pending application Ser. No. 292,902, filed July 5, 1963, entitled “Radar System,” now abandoned.

This invention relates generally to radar, and more particularly to a radar scanning antenna system.

In the field of navigation, terrain avoidance, anticollision, and aircraft landing approach radar systems, as well as, to some extent, fire control and automatic guidance radar systems, there is a severe need for radar and radar presentation which shows the observer what his eye would see in a given field of view but for fog, clouds, rain, snow, darkness, or other visual obstacles including physical structures.

Although the present invention finds particularly useful application in airborne terrain avoidance and routine or emergency landing approach radar, and although much of the discussion of particular examples herein relates directly thereto for purposes of clarity and a ready understanding of the invention, it is to be understood that the invention is not limited to such utilizations. Other applications, such as in PT boats, hydroplanes, or space rendezvous systems, will be readily visualized by the skilled artisan.

In the terrain avoidance radar systems heretofore available, an airplane or helicopter pilot in approaching, e.g., broken terrain in fog or a landing strip at night may have visual guidance through visible terrain obstacles and approach and runway lights. However, when these are periodically or suddenly obscured, the pilot has either to accept the temporary “blindness” or resort to instruments. The information from which is presented to him in a form totally different from the actual visual presentation to the eye through the airplane windshield. Typically, the instrument information is audio or visual by way of instruments mounted in the cockpit so that the pilot’s vision often must be directed from the windshield to an instrument panel. Furthermore, at best, no single such instrument heretofore available presents a desirable amount of information as to position, range through parallax or changing spatial relationships, and character of terrain, obstacles, and runway. The deficiencies and dangers of, as well as the difficulties of using the prior art systems in such situations, is manifest.

Accordingly, one of the objects of the present invention is to provide a television-type of vertical window presentation of the radar “picture” to the pilot so that when his forward vision is obstructed, he can view in the same general manner the same field of view with radar that he could, if not obstructed, see through the windshield.

Radar scanning antenna systems heretofore available have not been satisfactory for achieving the above objects because in order to provide satisfactory resolution with an effective frame rate which is high enough to show accurately the character of the rapidly approaching terrain, an extremely expensive and complex antenna system is required with its inherent weight, bulk and relative lack of reliability, and is therefore not a practicable system for airborne applications. In addition prior art antenna systems which provide good resolution do so with narrow beam antennas such that the scanning rate for the resolution must be compromised in order to achieve a useful range.

It is therefore another object of the invention to provide an antenna system with narrow beam resolution which is substantially unlimited in angular scanning rate, raster frame rate, and range; and which is mechanically relatively simple, rugged, adaptable to very small airframes, and inexpensive to manufacture, install and maintain.

It is another object to provide such a system which presents throughout a given solid viewing angle, a visual presentation having solid angle coordinates for target points therein, which relate in one to one correspondence with the solid angle coordinates of the actual target with respect, in both instances, to the eye of the observer.

It is another object to provide improved electromechanically and electronically scanned antenna systems for providing vertical window or horizontal window (P.P.I.) display systems.

Briefly, these and other objects are achieved in one example of the invention in which an antenna system is provided which includes a vertically oriented, radiating slot array which radiates a one degree thick horizontal fan beam along a given radiation pattern axis. The fan beam has, in this example, a width of approximately 30 degrees which is determined by the desired width of the radar field of view.

By periodically altering the velocity of the microwave energy propagating along the length of the waveguide slot array, the horizontal fan beam is shifted angularly 15 degrees above and 15 degrees below the radiation axis. In this manner, the angular regions in the entire radar field of view are all “illuminated” by a sweeping fan beam one degree thick and 30 degrees wide.

Similarly, a horizontally oriented receiving slot array is directed along the same axis and has a beam pattern in the shape of a one degree by 30 degree vertical fan which is angularly swept back and forth across the width of the transmitting beam.

It is apparent that there is at any instant of time a spatial coincidence between the two intersecting fan beams, and that the intersection or spatial coincidence defines a one degree by one degree “pencil.” The nature of the pencil beam is manifest if one considers that radar signals can be received only from an “illuminated” target located in the receiver beam. In the 30 degree by 30 degree geometry of this example, the high resolution intra beam pattern or raster type scanning is achieved if the horizontal fan, for instance, is relatively slowly shifted up and down while the vertical fan is rapidly, at
least thirty times faster, shifted back and forth across the horizontal fan beam. The beam scanning is achieved by either electromechanical effects in the slot array or electronically; and circuitry is provided for synchronizing the antenna scanning with the raster of a cathode-ray, vertical window projection display. A more detailed discussion of the circuitry is given below and it suffices here to note that for some applications of the invention the radar return may be presented to the display system without elaborate signal processing. For example, it is often adequate to project a representation of the signal return formed by the spot-to-spot brightness on the display as a direct or logarithmic function of the instantaneous echo signal strength. Further details of these and other novel features and their principles of operation, as well as additional objects and advantages of the invention will become apparent and be best understood from a consideration of the following description taken in connection with the accompanying drawings which are all presented by way of illustrative example only, and in which:

FIG. 1 is a schematic view of an example of a vertical window display, crossed beam radar system constructed in accordance with the principles of the present invention; FIG. 2 is a diagrammatic view of an example of a system of crossed antennas and their combined radiation paths; FIG. 3 is a frontal view of a waveguide antenna element constructed in accordance with the principles of the present invention; FIG. 4 is a cross-sectional view of the structure of FIG. 3 taken along the line 4--4 thereof; FIG. 5 is a longitudinal sectional view of a portion of the structure of FIG. 3 taken along the lines 5--5 thereof; FIG. 6 is a cross-sectional view of the structure of FIG. 3 taken along the lines 6--6 of FIG. 5; FIG. 7 is a frontal view of an alternative example of an electromechanically shifted waveguide antenna element; FIG. 8 is a cross-sectional view of the structure of FIG. 7 taken along the lines 8--8 thereof; FIG. 9 is a frontal view of an electronically shifted waveguide slot array antenna element; FIG. 10 and FIG. 11 are cross-sectional views of the structure of FIG. 9 taken along the lines 10--10 and 11--11 respectively thereof; FIG. 12 is a perspective view of a portion of the structure of FIG. 9; FIG. 13 is an elevational view of structure similar to that of FIGS. 9--12 illustrating the combination there-with of a plurality of novel phase shifters; FIG. 14 is a perspective view of an individual one of the phase shifters shown mounted in the overall assembly of FIG. 13; FIG. 15 is a longitudinal sectional view of the structure shown in FIG. 14 taken along the lines 15--15 thereof; FIG. 16 is a schematic view of a portion of an electronically scanned crossed field antenna system; FIG. 17 is a graph useful in discussing the principles of operation of the invention; Referring to the figures in more detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion only, and are thus presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and structural concepts of the invention. In particular, the detailed showing is not to be taken as a limitation upon the scope of the invention which is defined by the appended claims forming, along with the drawings, a part of this specification.

In FIG. 1, a transmitter 20 is shown with its output terminal coupled to a radiating waveguide antenna mem-

ber 22. Similarly, a radar receiver 24 is shown connected to the output terminal of a receiving waveguide antenna member 26. The waveguide antenna members 22, 26 may be affixed rigidly to a frame member, not shown, which may in a typical example be the actual airframe of the vehicle carrying the subject radar system. In any event, in accordance with a presently preferred organization of the invention, the two antenna members are mounted at approximately right angles to each other but in approximately the same plane in a manner such that both are adapted to have their main beam lobes directed forwardly, to the right as shown in the drawings, along generally a common scanning axis 28 which is normal to the plane in which the antenna members 22, 26 are mounted. Each of the antenna members is formed with a radiating aperture or an array of 60, in this example, radiating slots 30 in the face of the waveguide exposed toward the direction of the common scanning axis 28.

The horizontally oriented antenna member is adapted, as shown more clearly in FIG. 2, to which reference may now be made, to provide a receiving antenna fan-shaped beam 32 which has an angular dimension in the vertical forward plane of approximately 30 degrees and an angular dimension in the horizontal, cross dimension, of approximately one degree. The vertically oriented radiating waveguide antenna member is of the character designed to provide a transmitted fan-shaped beam 34 which has angular dimensions of approximately 30 degrees in the forward horizontal plane and approximately one degree in the vertical, thickness dimension. Since both fan-shaped beams 32, 34 are directed forwardly along the common scanning axis 28, and intersect at approximately orthogonally as shown, their intersection defining a one degree by one degree pencil beam 36.

Referring again to FIG. 1, an azimuth drive 40 is shown schematically as coupled or connected to the receiving waveguide antenna member 26 for causing the vertically oriented fan-shaped beam to be deflected back and forth horizontally, or in the direction of the thickness of the fan-shaped beam, about the common scanning axis 28. In this example, the deflection is systematic, preferably periodic, causing the beam to be deflected 15 degrees to the left of and 15 degrees to the right of the axis 28. The azimuth drive 40 is indicated here only schematically. Its actual nature and function will be described in more detail below. It suffices here to point out that it may be an electromechanical feature of the antenna member as for changing the effective phase velocity along its length or it may be a system of phase shifters for direction shifting the synthesized beam lobe electronically.

Similarly, a vertical drive 42 is connected to the radiating waveguide antenna member 22 and functions in one of the plurality of methods described in more detail below to deflect systematically the horizontally oriented fan-shaped beam up and down about the common scanning axis 28. Again, the magnitude of angular deflection may be approximately 15 degrees above and 15 degrees below the axis 28.

For purposes of providing a raster-like scan of the pencil beam 36 over the 30 degree by 30 degree solid angle to be probed or viewed, one of the antenna drives 40, 42 is adapted to achieve a significantly more rapid deflection about the axis 28, than is the other. To this end, for example, the azimuth drive 40 may operate to deflect the vertically oriented fan-shaped beam 32 back and forth horizontally across the axis 28 at approximately thirty times the deflection rate of the beam of the vertical drive 42. To achieve the desired programmed scanning technique or pattern, a raster synchronization network 44 is provided and is coupled, as shown, to both the azimuth drive 40 and vertical drive 42. The network 44 may also be coupled to the display 46 so that its included raster generator, not shown, may
generate an appropriate raster for a visual presentation having solid angle coordinates for target points on the display which relate in a one to one correspondence with the solid angle coordinates of the actual targets in the antenna field, with respect in both instances to the eye of the actual, real thing. As for

The signal output of the radar receiver 24 may be coupled substantially directly to the intensity control of the display system 46 so that the display raster will be relatively brighter, depending upon the magnitude of signal return of a particular segment of the forward solid angle scanned by the associated radar system. It may be noted that for greater realism in the visual display presented to the observer, the cathode-ray presentation may be intensity inverted with respect to the normal or conventional mode of presentation. That is, instead of the brighter signals representing stronger radar return; the brighter display points may be used to indicate the position of the weaker radar return signals. This may be utilized when or where desired for added realism in the display because the majority of physical obstacles as seen in reality by the observer are dark while the open spaces are relatively light in optical return.

Alternatively, the coupling the receiver output directly to the intensity control of the display system 46, a signal processing network 48 may be provided to utilize range information when desired. For example, signal time control techniques may be utilized to decrease automatically the effective intensity of all signals at close range or to intensity automatically signals received in the main beam from great distances. In this latter manner for example, the distant horizon may be continuously presented to the observer as an extremely useful, constantly available reference both for flying the carrying vehicle directly as well as for judging the nature and position of other obstacles presented to the display. For the signal processing network 48, a range synchronization network 50 may be provided which repetitively triggers the transmitter 20 and at the same time supplies a synchronizing signal to the signal processing network 48. An additional antenna system means cooperating with the network 48 may be provided, when desired, to resolve any ambiguities, which may occur in extreme cases, between a near target off the main beam and a distant target on the main beam.

It may be noted that no duplexing networks are indicated in FIG. 1 and are not generally needed, in accordance with the nature of the present invention, particularly in that the coupling between the two substantially perpendicularly oriented antenna members 22, 26 is such that very little of the transmitted energy finds its way directly into the receiving antenna. In other words, as pointed out, the two antenna waveguide members function substantially entirely independently of each other and this gives rise to some of the advantages discussed in more detail below.

It may further be noted that the array of slots in the horizontally oriented antenna member 26 are formed in a frontal narrow wall in an angularly staggered orientation, as shown; so that its radiation polarization is parallel with that of the longitudinally oriented slots in the broad wall of the vertically oriented antenna member 22.

In FIG. 2 which has been described above for purposes of description of the antenna beam patterns, a horizontally oriented receiving waveguide antenna member 26' is indicated as having associated therewith the vertical fan-shaped antenna beam 32. Similarly, a vertically oriented radiating waveguide antenna 23' is indicated for generating the horizontal fan-shaped beam 34. In this example, the radiating aperture in each of the waveguide antenna members 22', 26' is formed in the shape of a substantially continuous radiating slot 60 which extends over a major portion of the length of each of the antenna members. The radiating slit 60 in each case is formed in the broad side of each of the rectangular waveguide segments and is oriented obliquely, or slanted, so that near the input end or feed end 62 of each of the antenna elements the slit is disposed very closely to the longitudinal central line of the broad wall of the member and in which it is formed. The slit 60 then slants in a manner to be disposed progressively further away from the center line of the waveguide, along the length of each waveguide member away from the input end thereof. In this manner, a substantially even distribution of coupling between the associated fan-shaped antenna 32, 34 is achieved. The interior of the waveguide member is accomplished along the length of the waveguide member, since the percentage of coupling from the waveguide interior is minimum along the center line of the broad wall of the waveguide and maximum at a point approximately midway between the center line and one of the narrow walls thereof. Thusly the coupling percentage between beam and waveguide is very small near the feed end of the waveguide member and is substantially 100% at the opposite, terminated end of the waveguide member.

In this example of the invention, the antenna direction driving mechanism is electromechanical and comprises an electric motor 64 mounted on the waveguide member 22' and an electric motor 66 mounted on the waveguide member 26'. Each of the motors 64, 66 is coupled to an elongated shaft 68, 70, respectively, which includes a plurality of eccentrics along its length which are mechanically coupled to a like plurality of yokes 72 which resolve the rotary motion of the motor shafts into transverse motion which is coupled to antenna ridge elements, not shown, for inserting and removing them relative to the broad wall of the waveguide members opposite to the broad wall shown in the figure through which the radiating slits 60 are formed. Details of the eccentrics are described in more detail in subsequent figures. It may be noted here, however, that one of the electric motors 64, 66 is typically adapted to rotate at an angular velocity of approximately 30 times that of the other in order to achieve the raster-like scanning of the 30 degrees by 30 degrees solid angle with the pencil beam 36. It should be noted that in the continuous, elongated radiating slot case, the common axis 28 is generally directed away from the feed ends 62 of the members 22', 26' since this type of radiating slot tends to be more endfire in function.

In FIG. 3 an example of an antenna waveguide member 80, similar to either of those shown in FIG. 2, is illustrated, in a frontal plan view. A substantially continuous, elongated radiating slot 82 is shown extending over a major portion of the length of the member 80 and formed in one of the broad walls thereof. For purposes of control of the radiation distribution discussed above, the radiating slit 82 is disposed near the center line of the broad wall of the member 80 near the input end 84 thereof, and is gradually shifted along the length of the waveguide member until it is disposed at approximately one-half the distance between the center line and one of the narrow walls of the waveguide near the terminated end 86; the termination being achieved by a lossy plug 88 inserted therein. An electric ridge driving motor 90 is shown mounted on the rear surface of the waveguide member and a plurality of the yoke housing members 92 may be seen projecting from the sides of the waveguide member.

In accordance with the presently preferred structural approach to the construction of the antenna member shown in FIG. 3, the waveguide member 80 is chosen to have cross-dimensions which are smaller than those which would normally be chosen for the frequency range of operation and smaller than the remaining of the system; namely, that indicated by the connecting waveguide segment 94 which is coupled to the input end 84 of the waveguide member 80 through
appropriate flanges and a transition section 96. Although the waveguide member 80 is smaller than what is normally considered optimum, its dimensions achieve an above-cut-off condition for the frequency utilized. In a typical $k_a$ band system, the dimensions of the waveguide segment 94 are typically .622 by .311 inch, while those of the member 80 are .500 by .250 inch. The purpose of this choice of diminished dimensions is to slow the velocity propagation in the waveguide member 80. The waveguide ridge, not shown here, but which is illustrated in subsequent figures, increases the velocity of propagation and tends to cause it to reach the value normally associated with regular $k_a$ band waveguide.

Referring to FIG. 4, a cross-sectional view of the assembly of FIG. 5 is shown. The rectangular waveguide member 80 is illustrated with the radiating slit 82 formed in the frontal broad wall thereof. In the opposite broad wall, a longitudinally extending ridge opening 98 is illustrated. A transversely movable antenna ridge element 100 is provided which extends along substantially the entire length of the major portion mentioned above of the ridge opening 98, and may have a ridge opening 104 formed in the broad wall thereof, and is adapted to and in register with the ridge opening 98 of the member 80. Support for the ridge element 100 is provided by a pair of longitudinally extending vanes 106, 108 which are affixed along their rear edges to the broad wall of the waveguide-like member 102, which rear wall is longitudinally parted along its length between the supporting vanes 106, 108 to provide passageway for the connecting portion 110 of the ridge element 100.

The ridge element 100 is shaped in cross-section generally in the form of a T, as shown, with skirt sides extending rearwardly so that regardless of the extent of insertion thereof into the interior of the waveguide member 80, if electrically appears thereto as a solid rectangular ridge projecting from the rear wall of the waveguide member 80. The central connecting portion 110 of the ridge element extends through the space between the supporting vanes 106, 108 and is connected to a yoke 112 which receives angular motion of the eccentric portion 114 of the driving electric motor 136 through a sliding motion for inserting and withdrawing the ridge element 100 from the interior of the waveguide member 80.

The yoke housing and support member 92 is utilized to secure the waveguide member 80 and the waveguide-like member 102 and at the same time to support slidingly the rear portion 116 of the yoke 112 as it is driven by the eccentric portion 114. For this purpose, an opening 118 may be provided in the rear wall of the yoke housing member 92.

It is to be understood further to provide a finite longitudinal clearance between the side skirts of the ridge element 100 and the ridge opening 98, 104 to assure freedom of longitudinal motion without overloading the electric driving motor 90, and without abrassively damaging any of the affected parts. Because of the finite clearance, it is possible for significant amounts of microwave energy within the waveguide member 80 to be leaked deleteriously through the rear wall of the waveguide member 80. To prevent such deleterious effects, the longitudinal volume between the supporting vanes 106, 108 and the narrow walls of the waveguide-like member 102 is formed and adapted to define a radio frequency choke. To this end, the skirt-like portion of the ridge element 100 and the ridge-like portion of the ridge element 102 cooperate further to preclude leakage of microwave energy through the space between the connecting portion 110 of the ridge element and the adjacent faces of the supporting vanes 106, 108.

In operation, it may be seen that as the motor shaft 116 rotates, the yoke 112 is driven back and forth, as indicated by the motion arrow, in a manner to vary the degree of insertion of the frontal face of the ridge element 100 into the interior of the waveguide member 80. When the ridge element 100 is fully inserted to the extent indicated by the dashed lines in the figure, the propagation velocity along the length of the interior of the waveguide member 80 is at a maximum value and when the ridge element is fully withdrawn, as shown in the figure, the velocity is at a minimum value and has been found, in fact, to be of a lesser value than is the case for a segment of waveguide having the cross-dimensions of the waveguide member 80 without a ridge associated therewith. In other words, the waveguide member 80 when "negatively ridged" functions electromagnetically oppositely to a normally ridged waveguide.

Referring to FIG. 5, a simplified longitudinal sectional view of a portion of the feed end 84 of the waveguide member 80 is illustrated. A ridge opening 96 is illustrated to the extent that the connecting flanges between the waveguide member 80, its feed end 84 thereof, and the transition section 96 have been deleted. The radiating slit 82 is clearly illustrated as is the ridge element 100, but without its associated and supporting structure. The ridge opening 98 is illustrated as well as is the ridge-like element 100 shown in the figure as being substantially withdrawn from the interior of the waveguide member 80.

The dashed lines indicate the position of the frontal ridge of the edge element 100 when it is fully inserted into the interior of the waveguide. A mechanically flexible strip 118 is affixed at one edge of the waveguide ridge opening 98 to the inner rear wall of the waveguide member and is bending-momentwise pre-stressed along its length so that its opposite end continuously is urged into electrical contact with the front surface of the ridge element 100.

In this manner, electrical energy propagating along the length of the waveguide member 80 and the transition section 96 does not see the abrupt end of the ridge element 100 when it is extended fully into the waveguide. Similarly, when the ridge element is withdrawn to its fullest extent from the waveguide, the propagating energy does not see the abrupt edge of the end of the ridge opening 98.

In FIG. 6, the structure shown in longitudinal section in FIG. 5 is shown in cross-section, again in a somewhat simplified view. The waveguide member 80 with its radiating slit 82 formed in its frontal broad wall and its ridge opening 98 formed in its rear broad wall is illustrated. Again, the ridge element 100 is shown in its furthermost withdrawn, i.e., with the transition metal strip 118 shown bearing against its upper, frontal surface. As before, the dashed lines indicate the maximum insertion of the ridge element into the interior of the waveguide member 80.

In FIG. 7 an alternative example of an antenna element assembly 120 is illustrated. This is a velocity shifted to velocity shifted by the insertion and withdrawal electromechanically of the ridge element, it differs mechanically significantly from the examples discussed in connection with the last previous figures. In FIG. 7, an antenna waveguide member 122 with a transition feed end 124 is shown mounted upon a frame member 126. The waveguide member 122 in this example is provided with a single opening 128 in its frontal broad wall for both ridge element insertion and radiation emission. A unitary ridge element member 130 is mounted in a rocker-like fashion to a plurality of supporting bearings 132 which are affixed rigidly to the frame member 126. A pivot pin 134 is provided through the bearings 132 and the ridge element member 130 to provide pivotal rocker support for the latter. A driving electric motor 136 is mounted on the frame member 126 and is coupled through a
pair of yokes, not shown in this figure, to drive reciprocally the ridge element member \textbf{130}.

Referring to FIG. 8, the cross-sectional view therein of the structure shown in frontal elevational view in FIG. 7 illustrates clearly the unitary opening \textbf{128} for slit-type radiation coupling between the interior of the waveguide antenna member \textbf{122} and the antenna beam. In this view, which is similar in all other respects to the structure shown in FIG. 7, a beam forming antenna reflector \textbf{140} is shown affixed longitudinally to the upper narrow wall of the waveguide member \textbf{122} and the frame member \textbf{126}. The unitary ridge element member \textbf{130} is shown in its pivotal relationship about the pivot pin \textbf{134} which is journaled within the supporting bearing \textbf{132} which in turn is rigidly mounted to the frame member \textbf{126}. An operating extension lever arm \textbf{142} is affixed to the ridge element member \textbf{130} at its edge oppositely disposed from the inserting ridge face \textbf{144}. The lever extension arm \textbf{142} has a slot \textbf{146} formed therein which is disposed in a cam following relationship with an eccentric portion \textbf{148} of the shaft \textbf{150} of the driving motor \textbf{136}.

In operation, as the shaft \textbf{150} of the driving motor \textbf{136} is rotated, the cam following action between the eccentric portion \textbf{148} and the slot \textbf{146} in the lever extension arm \textbf{142} causes the insertion portion of the ridge member \textbf{122} to be inserted and withdrawn repeatedly through the ridge opening \textbf{128} in the front broad wall of the waveguide member \textbf{122}. As described in connection with the earlier figures, the further portion \textbf{144} is inserted into the interior of the waveguide member \textbf{122} the higher the propagation velocity of the microwave energy therein; and conversely, the further it is withdrawn the lower the velocity of the microwave energy in the waveguide. The finite spacing between the elongated frontal edge \textbf{152} and the ridge opening \textbf{128} provides an elongated aperture for leakage-type of coupling between the waveguide and the antenna beam. Further in this connection, it may be noted that the frontal edge \textbf{152} cooperates with the beam forming reflector \textbf{140} to provide some impedance matching between the beam and the waveguide.

In FIG. 9 an electronically shifted radiating waveguide antenna element \textbf{160} is shown which includes a length of waveguide \textbf{162} and a supporting frame structure \textbf{164}. Not shown in this figure are a plurality of electronic phase shifters for achieving the control of beam direction. The length of waveguide \textbf{162} in this example may be full dimension waveguide since the beam direction control is achieved by means other than an inserted ridge. The waveguide \textbf{162} has a formed therein along a major portion of its length an array of radiating slots \textbf{166}. Again, as with the radiating slot in the previously illustrated examples, the slots \textbf{166} are disposed laterally adjacent to the center line of the frontal broad face of the waveguide \textbf{162} near its feed end \textbf{168}, and are spaced approximately half way between the center line and the narrow walls near the terminated end \textbf{170}. The staggered relationship of the slots are on opposite de of the waveguide, \textbf{160} is chosen for the nominal in-phase relationship therebetween which is thereby achieved because adjacent ones of the slots are on opposite sides of the waveguide, which would cause them to be out of phase but for the fact that they are longitudinally spaced at half-wave length intervals. Again the magnitude of lateral offset of the disposition of the slots \textbf{166} from longitudinal center line of the frontal broad wall of the waveguide \textbf{162} determines the percentage of coupling between the antenna beam and the waveguide. The slots \textbf{166} have a width of approximately 0.003 inch thick, to provide microwave conduction continuity throughout the interior surfaces of the length of waveguide while permitting the "propagation" therethrough of rapidly varying magnetic fields—of the order of megacycles per second. Alternatively, the walls of the waveguide segment may be relieved as shown, but in a manner to leave a foil thickness thereof against
which the slabs \(186\) may be cemented to assure an even smoother continuity of surface conductivity throughout the phase shifter. The outer surface of each of the dielectric panels or slabs \(186\) may be substantially coplanar with respect to the outer surface of its associated broad waveguide wall. A low reactance coil \(188\) is then wound about the body of the phase shifter \(184\) along that axial segment thereof where the dielectric slabs \(186\) are implanted to form a means for providing an axially directed ferrite magnetizing magnetic field in response to current sent through the conductor of the coil \(188\). In practice, the slabs \(186\) have been found to function particularly well both electrically and mechanically structurally when fatal \(182\), the magnetic field is applied in a manner to cause a 360° phase shift in the propagating microwave energy.

Referring to FIG. 16, a schematic diagram of an antenna element assembly \(198\) is illustrated which utilizes the antenna waveguide element \(160\) of FIG. 9 et seq. A plurality of approximately sixty ferrite phase shifters \(184\), mechanically directly affixed cooperatively to the waveguide element \(160\) are shown schematically. In practice, appreciably greater angles than \(30°\) of scan deflection can be obtained with a 60 slot array in one meter long \(k\), antenna waveguide element. Furthermore, the number of slots required for \(30°\) deflection range can be reduced—particularly if a matching horn is affixed over each slot.

Each of the ferrite phase shifters \(184\) is designated in the figure by a subsequent number to identify its relative position from the feed end \(168\) of the waveguide element \(160\). Accordingly, the ferrite phase shifter nearest the feed end \(168\) is designated \(184(0)\); the next is designated \(184(1)\); the phase shifter approximately one-fourth of the waveguide element length from the feed end is designated \(184(15)\); the phase shifter disposed approximately in the center of the waveguide element is designated \(184(30)\); the phase shifter disposed one-fourth of the way from the terminating end of the waveguide element is designated \(184(45)\); and finally the ferrite phase shifter disposed nearest the terminating end of the waveguide element is designated \(184(60)\).

In this example, which is somewhat simplified for purpose of explanation of the conceptual principles involved in the invention, it may be assumed that when none of the ferrite phase shifters \(184\) is energized by electrical currents through its energizing coil, not shown, the wave front of the emanating microwave energy resulting from excitation of the waveguide antenna element \(160\) may be represented as an undistorted, forwardly progressing linear \(156\). When the ferrite phase shifters \(184\) are energized in a manner to cause a 30° deflection of the wave front, it may be designated by the wave front line \(198\).

Coupled to the magnetizing coil of each of the phase shifters \(184(1)\) to \(184(60)\) is a function generator or phase shifter drive oscillator \(200(1)\) to \(200(60)\) respectively. Each of the oscillators \(200\) is, in this example, of the character to provide a repetitive sawtooth electric current waveform, the peak amplitude of which is such as to cause a 360° phase shift in its associated phase shifter \(184\). Each of the oscillators can be a compact Shockley diode type of oscillator with a relatively simple cooperating amplifier. Each of the oscillators is preferably free running and each has a progressively higher frequency of oscillation with the oscillator \(200(60)\) typically operating approximately 30 times faster than the oscillator \(200(1)\). The frequency increase is linear along the series of oscillators from oscillator \(200(1)\) to oscillator \(200(60)\), in a manner such that a given period of time the oscillator \(200(1)\) will achieve one cycle, the oscillator \(200(30)\) will achieve approximately 15 cycles, and the oscillator \(200(60)\) will achieve approximately 30 cycles. The set given period of time is typically that amount of time alotted for one 30° degree sweep of the direction of the antenna beam as indicated by the direction change or difference between the wave front line \(196\) and the wave front line \(198\). The accuracy of absolute frequency of each of the function generators is not critical; and their relative frequencies are maintained adequately accurate by virtue of them all being mounted in the same environment.

In operation, at the beginning instant of a cycle of the beam scanning, a reset signal is applied to each of the oscillators \(200\) from the rater synchronization network \(44\) (see FIG. 1) in a manner to assure that the phase of the oscillator's drive current from each of the oscillators is phase shifted such that the instant is zero. Accordingly, as indicated previously, under these conditions the wave front of the emanating microwave energy is undeflected and is as represented by the wave front line \(196\). As time progresses, however, to a point where the oscillator \(200(60)\) has completed one cycle of its sawtooth magnetic current output, the microwave energy propagating through the phase shifter \(184(60)\) will have been phase shifted 360 degrees relative to that propagated through the phase shifter \(184(0)\). If the length of the waveguide antenna element \(160\) is 60 wavelengths for the particular structural characteristics considered, it is apparent that the wave front line will have shifted approximately one degree.

This point in time is indicated in FIG. 17 by the column of phase shift graphs headed by the legend "One Degree Deflection." The sawtooth graphs in each of the columns of FIG. 17 indicate the number of cycles of oscillation achieved by the oscillator associated with the phase shifter to which the individual graphs are related by a horizontal dotted line. Accordingly, it may be seen that the graph \(202\) is associated with and represents the phase shift versus time achieved by the phase shifter \(184(60)\) as a result of electrical current supplied by the oscillator \(200(60)\). Similarly, a graph \(204\) illustrates the magnitude of shift achieved by phase shifter \(184(45)\); note that it is approximately three-fourths of the amount achieved by the full cycle of the graph \(202\). In like manner, the graphs \(206\) and \(208\) illustrate that the phase shifters \(184(30)\) and \(184(15)\) have each at this point in time achieved one-half and one-quarter, respectively of a full cycle of phase shift.

Referring to the second column of graphs in FIG. 17 which are headed by the legend "Six Degree Deflection," it is seen that at this point in time referenced to the instant of time at which the reset signal previously described was applied to the oscillators \(200\), it may be seen that the phase shifter \(184(60)\) has gone through six 30 degree phase shift cycles, as indicated by the graph \(210\). The graph \(212\) associated with the phase shifter \(184(30)\) illustrates that the middle phase shifter has effected three 30 degree cycles of phase shift on the microwave energy propagated through it.

In like manner, the phase shift drive oscillators \(200\) are all permitted to run freely until the oscillator \(200(60)\) has achieved approximately 30 cycles as illustrated by the graph \(214\) in the third column of FIG. 17. At this point in time, the phase shifter \(184(60)\) has suffered thirty cycles of 300 degree phase shift. Similarly, the phase shifter \(184(45)\) has exerted 22½ cycles of phase shift on the microwave
Similarly, each of the shifters 184 progressively down to
the phase shifter 184(1) has exerted a linearly decreasing
amount of total phase shift on the microwave energy prop-
gated through it. The phase shift 184(1), for example, has
at the time indicated, exerted one-half of a 360 de-
gree cycle of phase shift of microwave energy propagating
through it.

Assuming that 30° of phase shift is the desired amount,
the reset signal is at this time impressed upon all of the
oscillators to set them all at zero output current thereby
bringing the scan angle back to zero again for the begin-
ing of a new progressive scan angle sweep.

Although the principle of operation has been accurately
presented, it may be noted that in practice the ferrite phase
shifters 184 are typically of the character to exert a rela-
tively high magnitude of phase shift on microwave energy
propagating there through when the magnetization in the
ferrite is at a minimum; and that the magnitude of phase
shift may be considered to decrease as the magnetizing
current is sent through its magnetizing coil. In like man-
er, it is clear that the array of phase shifters 184 may be
arranged and adapted with respect to the array of radiat-
ing slots, in the waveguide to have respective mag-
netizing coils not energized, the wave front line may be
deflected 15 degrees in one direction, and after a full
period between reset signals, it is deflected 15 degrees in
the opposite direction. In any event, the time typically
utilized in constructed examples of the invention between
reset signals, is approximately one millisecond for the
rapidly scanning waveguide antenna element and approxi-
mately 30 milliseconds for the slower scanning antenna
element. It may be noted that if the time between reset
signals is increased in a given case, the scan angle will be
increased correspondingly.

It is further to be noted as a general advantage of the
antenna systems heretofore disclosed, that they achieve
wide angle and, cooperatively, wide solid angle raster
scanning with striking conservation of the microwave spec-
trum. Additionally, when greater resolution is desired or
monopulse type of operation is utilized, frequency scanning
techniques may be readily employed or any number of
totally independent beams, each at a different frequency,
may be generated and used simultaneously with the same
antenna system.

There have thus been disclosed a number of structural
aspects of different examples of a three-dimensional radar
system which achieve the objects and exhibit the advan-
tages set forth heretofore above.

What is claimed is:
1. An electromechanically beam direction shifted wave-
guide antenna member comprising: a length of waveguide
adapted to radiate microwave energy in a substantially
even distribution along a predetermined major portion of
said length, said length of waveguide having a predeter-
mined nominal velocity of energy propagation along its
length; a longitudinal ridge element coupled to said length
of waveguide and being transversely movable and insert-
able therein to affect the velocity of energy propagation in said waveguide thereby to shift the angular
direction of emanation of said distribution of microwave
energy, and a thin flexible strip of metal having a width
approximately equal to that of said ridge element bridging
the step between said ridge element and the wall of said
waveguide.

2. The invention according to claim 1 in which said
waveguide is formed to define at least one radiation aper-
ture in one broad wall thereof and an elongated ridge
opening in the opposite wall thereof for receiving said
ridge element and which includes: a frame member affixed
to said waveguide; ridge driving means carried by said
frame member and connected to said ridge element for
periodically altering the magnitude of lateral insertion thereof into said waveguide, the effective thickness of said
waveguide wall being a finite magnitude whereby the innermost extending surface of said ridge element may be
moved laterally between limits which are disposed to
either side, that is, internally or externally of the inner
surfaces of said opposite waveguide wall thereby to cause
to said waveguide to have respectively a propagation
velocity selectively greater and less than said nominal
velocity.

3. The invention according to claim 1 in which said
waveguide is formed to define at least one elongated, co-
operating ridge opening and radiation aperture in one
broad wall thereof for receiving said ridge element and said
opening for microwave slot coupling through said one broad
wall and which further includes: a frame member affixed to
said waveguide; ridge driving means carried by said frame
member and connected to said ridge element for period-
ically altering the magnitude of lateral insertion thereof
into said waveguide, the effective thickness of said wave-
guide wall being a finite magnitude whereby the innermost
extending surface of said ridge element may be moved
laterally between limits which are disposed to either side
of, that is internally or externally of the inner surfaces of
said one waveguide broad wall thereby to cause to said
waveguide wall to have respectively a propagation velocity
selectively greater and less than said nominal velocity.

4. The invention according to claim 2 which includes
means coupled to said ridge element and said waveguide
for substantially precluding the radiation of leakage en-
ergy from said waveguide through the longitudinal gap
between said ridge element and said elongate ridge open-
ing in said opposite wall.

5. The invention according to claim 4 in which said
means for precluding leakage radiation includes a radio
frequency choke structure coupled to said opposite wave-
guide wall, said ridge element, and said frame member,
and defining an elongated ridge member for said radio
frequency choke cavity.

6. The invention according to claim 4 in which said
ridge driving means comprises: an elongated cam shaft
rotatably affixed to said frame member and having a
plurality of eccentric, with respect to the axis of said
shaft, cam portions disposed on its length, said cam por-
tions being substantially mutually in angular union;
a like plurality of cam following yokes connected to respec-
tive ones of said cam portions and to said ridge element;
sliding bearing means carried by said frame member for
permitting transverse motion of said cam following yokes
whereby said ridge element is moved into and out of said
waveguide in accordance with the rotation of said shaft.

7. A three-dimensional radar system of the character
including an antenna system which provides two sub-
stantially orthogonally intersecting fan-shaped beams, and
comprising an electromechanically beam direction shifted
waveguide antenna member including: a length of wave-
guide adapted to radiate microwave energy in a sub-
stantially even distribution along a predetermined major
portion of said length, said length of wavelength having a
predetermined nominal velocity of propagation along its
length, said waveguide being formed to define a com-
bined radiation aperture and ridge opening along said
major portion; a frame member for carrying said wave-
guide antenna member; a transversely movable elongated
ridge element supported by and rotatable about a longi-
tudinal axis at rest with respect to said frame member;
ridge driving means for moving and inserting said ridge
element into said waveguide through said radiation aper-
ture and ridge opening, said driving means being spatially
related to define a longitudinally ex-
tending radiation leakage type aperture along said major
portion of said waveguide antenna.

8. The invention according to claim 7 in which said
ridge driving means includes a rotatable shaft mounted
on said frame member and having at least one cam thereon;
a cam following yoke interconnected be-
tween said shaft and said ridge element and adapted to
move said ridge element into and out of said length of
waveguide wall.
waveguide in accordance with the rotary motion of said eccentric cam.

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