

Jan. 3, 1961

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2,967,301

SELECTIVE DIRECTIONAL SLOTTED WAVEGUIDE ANTENNA

Filed Oct. 15, 1957

4 Sheets-Sheet 1

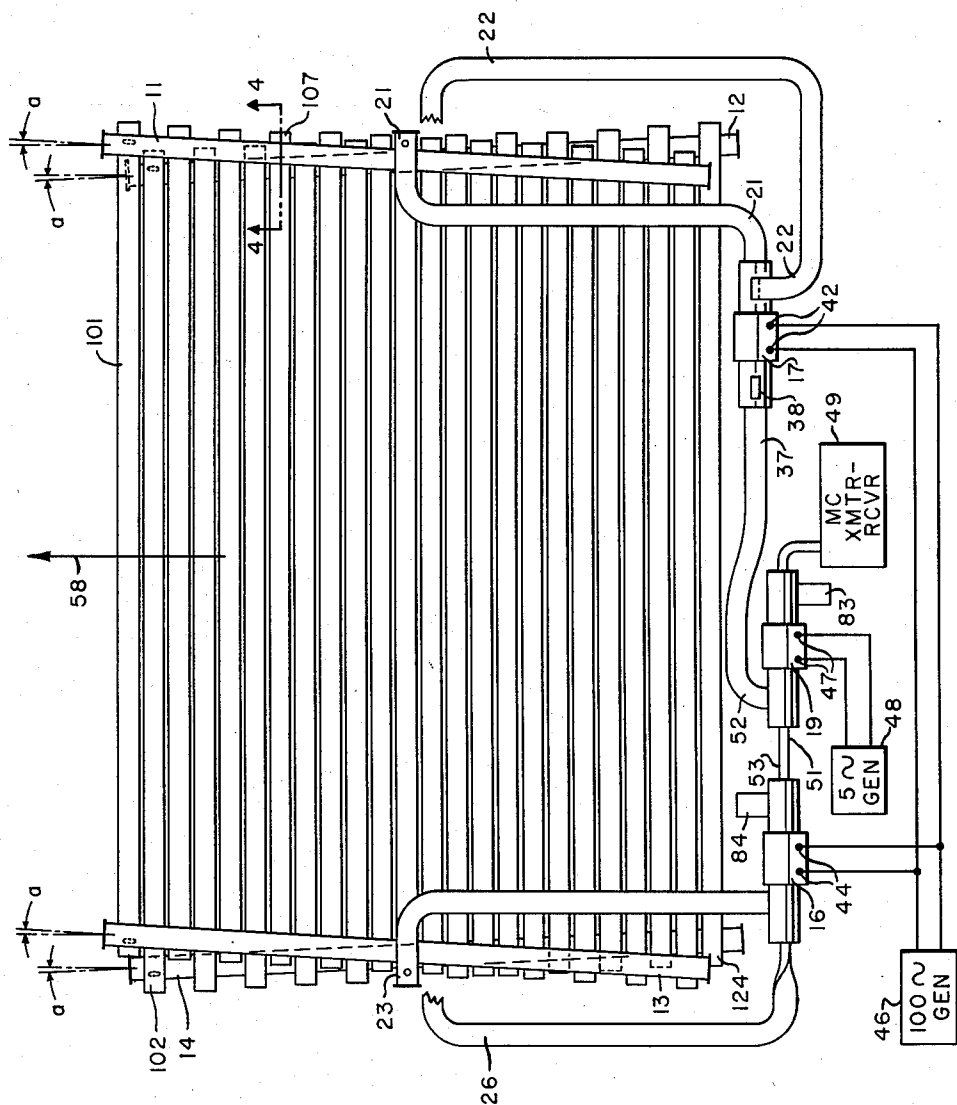


FIG. 1

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4 Sheets-Sheet 2

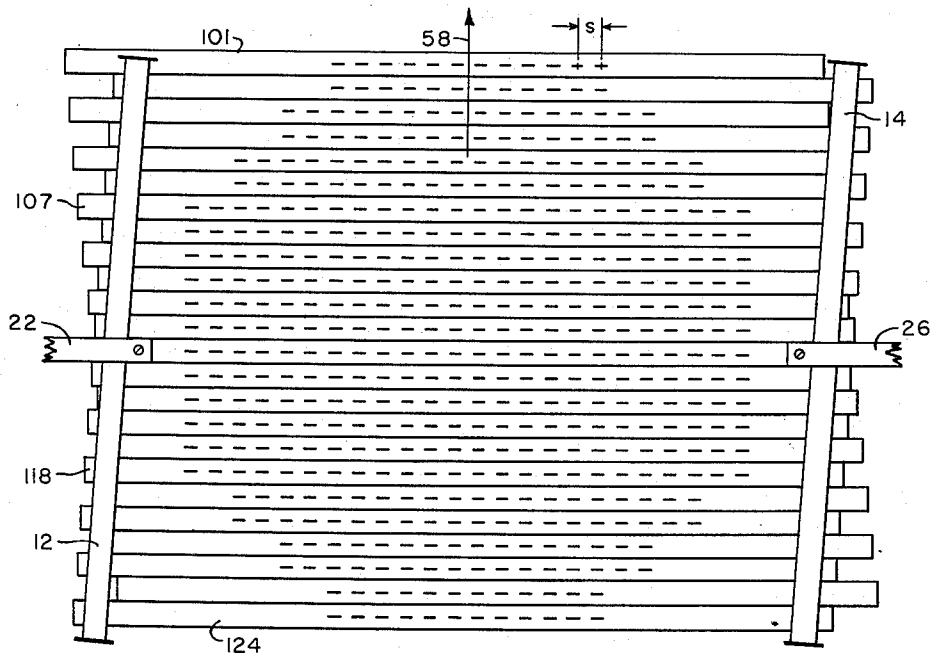


FIG. 2

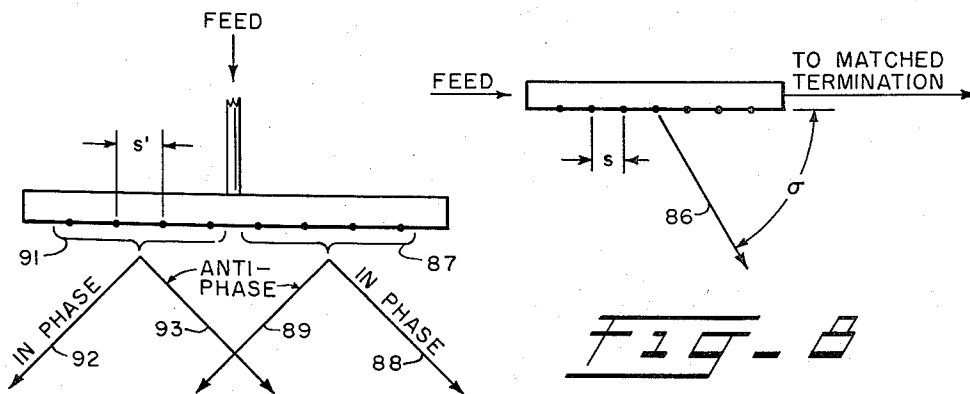


FIG. 3

FIG. 4

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4 Sheets-Sheet 3

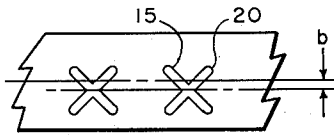


FIG. 3

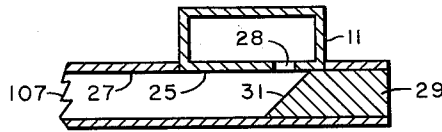


FIG. 4

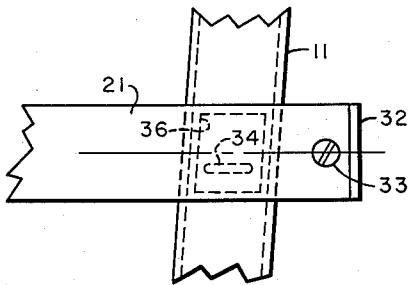


FIG. 5

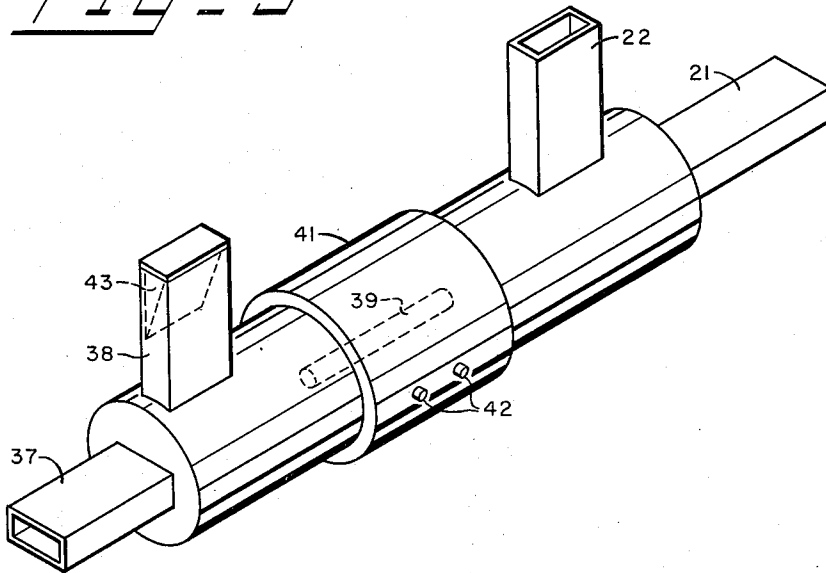


FIG. 6

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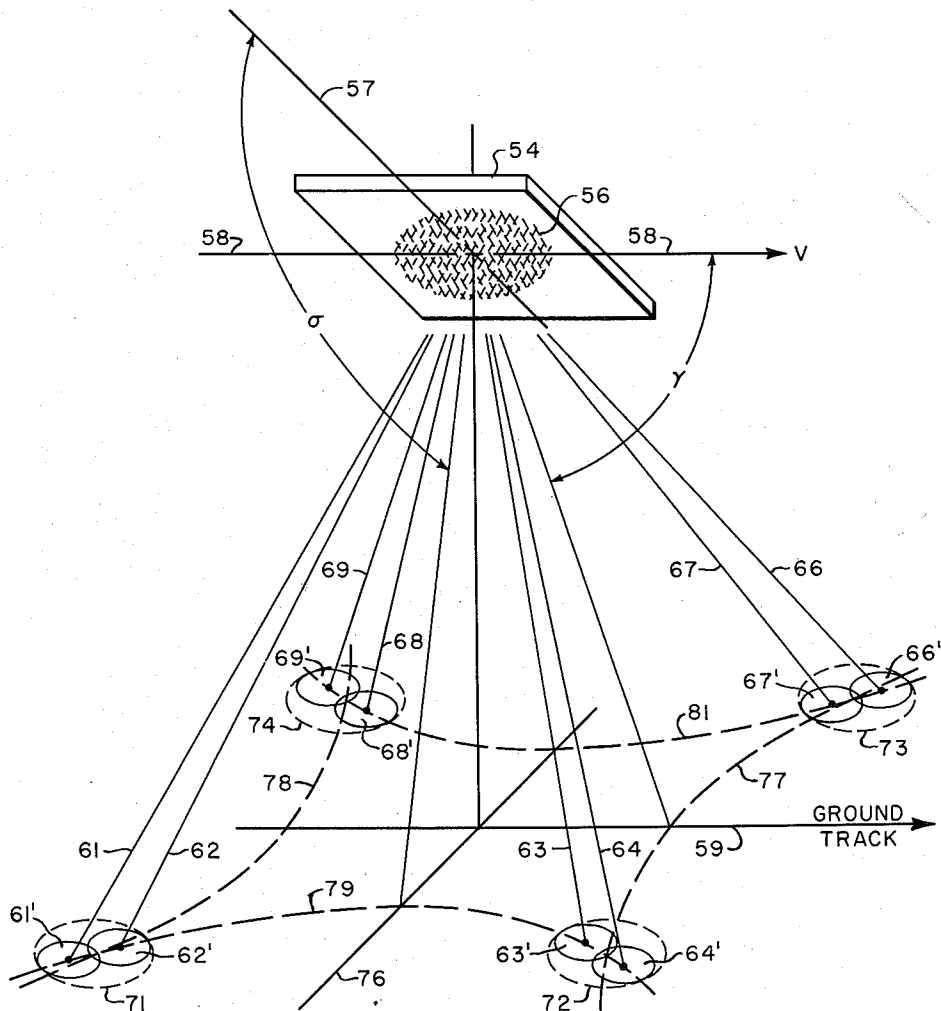


FIG. 7

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2,967,301

SELECTIVE DIRECTIONAL SLOTTED WAVEGUIDE ANTENNA

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12 Claims. (Cl. 343-771)

This invention relates to microwave beam antennas and more specifically to such an antenna comprising a planar array of radiators.

In one form of aircraft microwave equipment, several pulsed beams are directed toward the earth and Doppler information is extracted from their echoes. From this information are developed navigational data such as aircraft ground speed, drift angle and vertical velocity. This equipment requires a specialized antenna having certain functions, one form of which is the subject of this invention.

This planar antenna is stabilized or automatically maintained pointed in the direction of the aircraft velocity. The microwave radiation from the antenna consists of four beams which, in level flight are directed so that two are pointed down and forward, striking the earth on opposite sides of the ground track and equally distant therefrom. The other two beams are pointed down and backward at an angle equal to the forward angle, and also equally distant from the ground track. Each beam is dual, consisting of two lobes positioned approximately in a fore-and-aft line and separated only slightly so that their patterns intersect each other.

The planar antenna comprises a number of parallel linear arrays in a plane. Each linear array is fed alternately at either end, the end not being fed always being match terminated. The linear arrays are fed by a number of feed waveguides and the microwave energy is switched into these feed waveguides in one or more selected time sequences. The feed waveguides are positioned approximately in the antenna plane and approximately at right angles to the parallel linear arrays. However, the feed waveguides depart from the right angle relation by small angles in order to split each beam of microwave radiation into its two intersecting lobes.

The microwave radiators of the parallel linear arrays are confined to an area which is approximately circular, this circular form providing maximum microwave effectiveness for a given radome aperture area.

During the intervals between transmitted pulses, when echoes are received by the antenna, the echoes are transmitted through the feed waveguides and microwave switches to the microwave receiver. There the Doppler information contained in the microwave echoes is extracted and a Doppler frequency, μ , is derived representing aircraft velocity V in accordance with the relation

$$\mu = \frac{2V}{\lambda} \cos \gamma \quad (1)$$

in which λ is the microwave length in free space and γ is the angle between the microwave beam and the direction of aircraft motion, or the "looking" angle.

The mode of operation in reception is completely reciprocal with the mode in transmission so far as the antenna and associated switches are concerned, so that it is necessary only to describe one mode. Therefore in the following detailed description only the transmission

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mode will be described in full and the reception mode will be mentioned generally.

One purpose of this invention is to provide a microwave antenna suitable for use with aircraft equipment simultaneously measuring ground speed, drift angle and vertical velocity.

Another purpose is to provide an antenna emitting four dual beams of microwave radiation.

Another purpose is to provide an antenna including microwave switches for emitting time and space patterns composed of eight lobes of radiation.

Another purpose is to provide a microwave antenna requiring a minimum radome aperture.

Another purpose is to provide an aircraft antenna for measuring ground speed, drift angle and vertical velocity, the antenna being frequency compensated and stabilized to be velocity direction.

Further understanding of this invention may be secured from the detailed description and associated drawings, in which;

Figure 1 is a plan view of the non-radiating side of the planar antenna of the invention.

Figure 2 is a plan view of the radiating side of the planar antenna.

Figure 3 depicts a form of radiator for radiating a circularly polarized microwave field.

Figure 4 is a cross section taken on the line 4-4 of Fig. 1 and depicts a microwave waveguide transition for use in feeding the linear arrays.

Figure 5 depicts a microwave waveguide transition for use in feeding the feed waveguides.

Figure 6 depicts one form of microwave switch.

Figure 7 illustrates the operation of the planar antenna and shows the arrangement of its eight lobes of radiation.

Figure 8 illustrates the operation of one of the parallel linear arrays.

Figure 9 illustrates the operation of a feed waveguide regarded as a microwave linear array.

Referring now to Figs. 1 and 2, the planar microwave antenna of this invention comprises 24 linear arrays, arranged parallel in a plane, the first and last being indicated by the reference characters 101 and 124. The 24 linear arrays are fed with microwave energy through four feed waveguides 11, 12, 13 and 14. Microwave energy is supplied to these feed waveguides through two lobeing microwave switches 16 and 17 which are in turn supplied through a beaming microwave switch 19.

The 24 linear arrays are identical except for the number of radiators in each. Each linear array is made of a rectangular waveguide suitable for the microwave frequency employed. For example, for a frequency of 13.5 kilomegacycles per second and for use over a 100 mc.p.s. band width the waveguide has internal cross sectional dimensions of 0.471 inch and 0.153 inch, with a wall thickness of 0.040 inch. Each linear array is about 20 inches long and is closed at both ends by tapered metal plugs. Each linear array is provided with a single longitudinal row of microwave radiators equally spaced apart by the distance s , which is so selected as to provide successive equal differences of

$$\frac{\pi}{2}$$

radians in the phases of the microwave energy applied to the radiators. All radiator couplings in each array and in all arrays are of the same sense and also of the same magnitude, so that all of the 24 arrays are inphase resonant arrays with exponential illumination. As example, the radiators of an array are shunt slots equally spaced longitudinally in one waveguide broad face and laterally equally spaced from the longitudinal center line of the face. As shown in Fig. 2, the 12 linear arrays, 107 to 118,

are identical, each having 24 shunt radiating slots, the four flanking arrays have 20 slots, the four arrays outside these have 16 slots, while the four arrays at the edges of the planar array have only 12 slots.

In place of shunt slots as radiating elements of the linear arrays, any other type of radiator may be used. One type which has been found useful in reducing reflections from raindrops is that providing circular polarization of the radiated microwave energy. One form is depicted in Fig. 3. It comprises a cruciform opening cut in one broad face of the rectangular waveguide, the center of the cross being offset from the median line of the rectangular waveguide by a coupling distance b . The opening may be considered as a combination of two slots 15 and 20 making an angle of 90° with each other and a 45° angle with the median line. Slots at angles other than 45° may alternatively be used.

In the operation of this radiator, it is fundamental that a slot radiates most strongly when the direction of the current which would flow in the waveguide in the absence of the slot is at right angles to the slot. As a TE_{10} field passes through the waveguide in the figure, the current direction at the slot rotates, passing through 90° in one-quarter cycle. Therefore the cruciform radiator radiates as a dipole first from one slot, then from the other, then from the first slot with opposite polarity, etc. Therefore the radiated energy observed at any point in space will change its polarization continuously in time, this behavior being termed elliptical polarization and at selected adjustment becoming circular polarization. It therefore is useful in reducing reflection from rain.

The 24 linear arrays are rigidly secured to a supporting frame, not visible in the drawings, so that small spaces are left between adjacent linear arrays. The linear arrays are arranged so that, in the direction perpendicular to the arrays, the slots are aligned. The linear arrays are so spaced apart and so fed that the phase difference in space near the planar array of the radiations from two alternate slots in a line perpendicular to the arrays is π radians.

The general arrangement of the shunt radiating slots in the 24 linear arrays is, as shown in Fig. 2, in one plane face of the planar array, designated as the lower or radiating face. The area comprehending these slots has an octagonal perimeter which approximates circular form. This form of radiating area is selected because, when the perimeter is circular as this perimeter approximately is, the maximum radiation is secured through minimum radome aperture area.

The four feed waveguides 11, 12, 13 and 14 are basically identical. Each is made of the same rectangular waveguide as the linear arrays. Each is short-circuited at both ends by metal plates and is fed at the center, the feeds being from connecting waveguides 21, 22, 23 and 26. Feed waveguides 11 and 13 are positioned on the lateral edges of the upper or nonradiating face of the planar array, while feed waveguides 12 and 14 are positioned on the lateral edges of the lower or radiating face. Each feed waveguide is connected to feed every other linear array. Feed waveguide 11 feeds the same linear arrays as are fed by feed waveguide 13, and feed waveguide 12 feeds the same linear arrays as are fed by feed waveguide 14.

Described in another way, each linear array is connected at both ends to feed waveguides. Linear array 101 and all odd-numbered arrays are connected to feed waveguides 11 and 13, while the remaining even-numbered arrays are connected to feed waveguides 12 and 14.

Figure 4 depicts a cross section of the transition between linear array 107 and feed waveguide 11. It illustrates the transition employed at all junctions between a linear array and a feed waveguide. Linear array 107 is cut out to permit insertion of the feed waveguide 11 so that the lower wall 25 of the latter becomes a continuation of the upper wall 27 of the former. The lower wall 25 of feed waveguide 11 is provided with a shunt

slot 28 coupling the interior of the feed waveguide 11 to the interior of the linear array 107. The field transition between the two waveguides is impedance matched by a metal wedge 29 which closes the end of the linear array waveguide 107. Wedge 29 is provided with an inner surface 31 making a 45° angle and positioned at the location of the coupling slot 28.

The four feed waveguides are not positioned exactly at right angles to the linear arrays but are at angles of $3\frac{1}{2}^\circ$ thereto, as indicated by the angles a , Fig. 1. Thus, in the figure the upper end of right upper feed waveguide 11 is canted toward the right while the upper end of right lower feed waveguide 12 serving the same edge of the planar array is canted toward the left. Also the upper end of left upper feed waveguide 13 is canted toward the right while the upper end of left lower feed waveguide 14 is canted toward the left. This causes such a difference in the feed phases of the two feed waveguides on the same edge as to generate distinct lobes, as will be explained in detail in describing the operation of the antenna.

The rectangular connecting waveguides 21, 22, 23 and 26 joining the feed waveguides 11, 12, 13 and 14 to the lobing switches 16 and 17 are made of standard rectangular waveguides suitable for the microwave frequency band to be transmitted. Each feed waveguide is fed at its center from its connecting waveguide through a matched transition.

The construction of this transition is detailed in Fig. 5. Connecting waveguide 21 is terminated in a short circuiting plate 32 which, together with capacitive screw post 33 in its upper face serves to match the transition. The lower face of the connecting waveguide 21 is provided with a shunt slot 34 and the upper face of the feed waveguide 11 is cut out in a rectangle 36. Thus slot 34 appears to the connecting waveguide 21 as a shunt slot but behaves in the feed waveguide 11 as a series slot.

The two ferrite lobing microwave switches 16 and 17, Fig. 1, and the beaming switch 19 are identical in construction. Details of lobing switch 17 are indicated in Fig. 6. Input microwave energy is applied to the switch through waveguide 37 and cannot enter side arm 38 because of its orientation. The switch contains an axial ferrite rod 39 surrounded by a coaxial solenoid 41 having terminals 42. When this solenoid is not energized and ferrite rod 39 is therefore not magnetized, microwave energy applied at waveguide 37 passes through without rotation and leaves by waveguide 21 with the same orientation as at input waveguide 37. The energy cannot enter side arm 22 because of its orientation. Also echo energy entering from waveguide 21 passes through without rotation and leaves by waveguide 37. Microwave echo energy entering by waveguide side arm 22 cannot enter waveguides 21 or 37 because of their orientations but does enter side arm 38 which has the same orientation as arm 22, where the energy is absorbed by the impedance-matching absorbent carbon block termination 43.

When the ferrite rod 39 is magnetized by energization of coil 41, microwave energy passing through the ferrite section is rotated 90° . Thus energy from waveguide 37 leaves by side arm 22. Echo energy entering from waveguide 21 is absorbed in arm 38 and echo energy entering from side arm 22 passes out waveguide 37.

The microwave switch coil terminals 42 and 44, Fig. 1, are connected in parallel to a lobing frequency generator 46. The coil terminals 47 of the beaming microwave switch 19 are connected to a beaming frequency generator 48. The frequencies of the alternating currents generated by these generators are, for example, 100 cycles per second and 5 cycles per second. In general, the two frequencies should be distinctly different, with the lobing frequency higher than the beaming frequency. The lobing frequency must, however, be substantially lower than

the lowest Doppler frequency which is to be developed from the echo signals.

The microwave input is applied to the beaming ferrite switch 19 from a microwave transmitter-receiver 49. The two microwave output arms 51 and 52 of the beaming switch 19 are connected to the microwave input arm 53 of the left lobing switch 16 and input arm 37 of the right lobing switch 17 respectively.

Figure 7 indicates the mode of use of the antenna of the invention and in particular indicates and defines the eight pencils or rays of radiation which the antenna is designed to emit. The planar antenna 54 having a lower radiating surface 56 is positioned in an aircraft so that its transverse axis 57 is generally parallel with the aircraft's transverse axis. The antenna longitudinal axis 58 is stabilized to the direction of aircraft velocity, but the means of stabilization means forms no part of the present invention. This antenna is additionally suitable for use in a system stabilized to the ground track, and to simplify description, Fig. 7 is drawn with the antenna velocity direction V and its fore-and-aft axis 58 parallel to the ground track 59.

The antenna emits eight rays or pencils of radiation 61, 62, 63, 64, 66, 67, 68 and 69, each about 4° in width and each indicated by its numbered center line. Each ray or pencil illuminates the earth in a spot, the eight spots being indicated by the solid circles 61', 62', 63', 64', 66', 67', 68' and 69'. The pencils of transmitted radiation are paired, each pair of pencils intersecting at their 1½ db power points. Each pair of intersecting pencils may be termed a beam, and the two pencils composing it may be termed its forward and after lobes. The ground illuminations of the four beams are generally depicted by the dashed circles 71, 72, 73 and 74. These four beams are symmetrically positioned about the ground track 59 and also about the transverse line 76 perpendicular to the ground track and under the center of the antenna.

The two forward beams may be considered as elements of a radiated cone having the antenna forward axis as its axis. Such a cone intersects the earth in a hyperbola 77, the cone half angle being designated γ . A similar cone, having the same γ angle in level flight, comprehends the two after beams and produces the earth intersection hyperbola 78. In a similar manner, the two beams 71 and 72 may be considered as elements of a side cone of half angle σ having the hyperbolic earth intersection 79, and the other two beams 73 and 74 may be regarded as elements of a side cone having the same half angle σ , the earth intersection being hyperbola 81.

At any instant, two and only two of the eight lobes are radiated, with sequence and timing as follows. Lobes 61 and 63 are radiated simultaneously. The radiation is then shifted to lobes 62 and 64, which are simultaneously radiated. These pairs are thus alternately radiated, alternating at a rate of 100 c.p.s. At the end of 1/10 second the radiation is shifted from beams 71 and 72 to beams 73 and 74, in which the same lobing action takes place, lobes 69 and 67 being radiated simultaneously, and alternating at 100 c.p.s. with lobes 68 and 66 radiated simultaneously. At the end of 1/10 second the action is returned to beams 71 and 72. The lateral transfer of radiation may be termed beaming, and is at the rate of 5 c.p.s.

In the operation of this antenna, when any individual linear array is fed at one end it is terminated in its characteristic impedance at its other end. Thus each linear array generates no standing wave but operates as a traveling wave array. Moreover, when alternate linear arrays are energized the remaining, unenergized arrays are terminated at both ends through their respective feed waveguides and two of the ferrite switches in absorbing matching impedances. This effectively prevents the unenergized arrays from reradiating due to stray pickup from the adjacent energized arrays.

The microwave circuits which selectively energize one

feed waveguide and simultaneously terminate the other three in their characteristic impedances are as follows. With beaming switch 19 solenoid terminals 47 unenergized, it transmits microwave energy from transmitter-receiver 49 out waveguide exit 51. With lobing switches 16 and 17 having their solenoid terminals 44 and 42 unenergized, the microwave energy passes through connecting waveguide 26 to feed waveguide 14 and from it to all even-numbered linear arrays such as array 102. At the same time the other ends of these arrays, being connected to feed waveguide 12, are connected through it and connecting waveguide 22 to switch 17, and are therefore terminated in the absorbing and matching stub 38. At the same time the right ends of odd-numbered linear arrays are terminated through feed waveguide 11, connecting waveguide 21, switch 17, waveguide 37 and waveguide 52 in the absorbing and matching stub 83 of switch 19. Also the left ends of the same odd-numbered linear arrays are terminated through feed waveguide 13, connecting waveguide 23 and switch 16 in the absorbing and matching stub 84. Similarly, in each of the other three positions of the lobing and beaming switches a selected other one of the feed waveguides is excited and the remaining three feed waveguides are absorptively match terminated.

It has been found, for simplicity of design, that the linear array direction and the average feed waveguide direction should be perpendicular to each other in the plane of the antenna. The feed waveguides may be considered as linear arrays, in each its series of connected linear arrays being considered as if it were a series of simple radiators. Then each feed waveguide, treated as a simple linear array, emits at least one cone of radiation while the 24 linear arrays, numbered 101 to 124 in Fig. 1, emit a cone of radiation. The only inphase radiation being at the intersection of these two cones, the radiation actually emitted is not one or two cones, but a narrow pencil or lobe at the cone intersection.

Since provision for circularly polarized radiation is required, and since such radiation can be obtained only from inphase arrays, one of the sets of arrays must be inphase. Frequency compensation is desired, but since the antenna is preferably stabilized to the aircraft velocity direction, frequency compensation is then necessary only in the antenna fore-and-aft direction. Such compensation is secured by a combination of linear array inphase and antiphase operation.

Based on these considerations, the preferred construction is with the 24 linear arrays positioned parallel to the aircraft and antenna transverse axes, and the feed waveguide average direction positioned parallel to the antenna longitudinal axis and therefore parallel to the aircraft velocity direction.

In an inphase linear array

$$\cos \sigma = \frac{\lambda}{\lambda'''} + \frac{n\lambda}{s} \quad (2)$$

in which σ is the end-fire cone half angle, λ is the microwave energy wavelength in free space, λ''' is the microwave length in the linear array, being equal to the wavelength within the rectangular guide in this example, s is the distance between radiators, and n is any integer including zero. A single cone is radiated when the dimensions are such that $n \neq 0$, $\cos \sigma > 1$, and is therefore imaginary.

It is found that, at desired σ and γ values, the largest and most economical radiator spacing s which can be employed without generating a second principal beam is a distance producing a phase difference of

$$\frac{\pi}{2}$$

radians between radiators. In an inphase array, the

phase progressions at the radiators from the feed end are then

$$0, -\frac{\pi}{2}, \pi, +\frac{\pi}{2}, 0, \text{ etc.}$$

The radiation of such a single linear array is as depicted in Fig. 8, the ray 86 being the normal element of the cone of half angle σ . The radiated beam 86 is in a direction away from the feed end. When the linear array radiator couplings are all the same, the operation of the linear array is similar when fed from either end. The 24 transverse linear arrays of the invention are of this design.

The radiation of an antiphase linear array is given by

$$\cos \gamma = \frac{\lambda}{\lambda''} + \frac{\lambda}{s} \left(n + \frac{1}{2} \right) \quad (3)$$

the direction of the radiated cone being toward the feed end. When s is given such value that the phase difference between radiators is

$$\frac{\pi}{2}$$

radians, the phase progression from the feed end is

$$0, \frac{\pi}{2}, \pi, -\frac{\pi}{2}, 0, \text{ etc.}$$

If an inphase and antiphase array be combined, cancellation of the

$$\frac{\pi}{2}$$

terms may be considered to occur, and an array having spacing of $0, \pi, 0, \pi$, etc. results, emitting two beams. One beam will have inphase attributes and the other antiphase attributes.

The four feed waveguides are so designed. In addition they are given graduated couplings to secure gable illumination and they are center fed so that each half behaves as above described. The center feed is in series so that the feed senses are opposed in the two halves of the array. The result is as indicated in Fig. 9, in which the right half 87 emits an inphase beam 88 and an antiphase beam 89. Also the left half 91 emits an inphase beam 92 and an antiphase beam 93. Since the beams 88 and 93 have the same γ angle they act as one beam and since they combine inphase and antiphase qualities the composite beam is frequency compensated. That is, the Doppler information derived therefrom is independent of variations in the microwave transmitting frequency. Similarly, beams 89 and 92 combine to form a composite frequency-compensated beam.

The above description has been on the basis that the feed waveguides, such as feed waveguide 11, Fig. 1, have been parallel to the longitudinal axis 58, and the wavelength λ'' has been on that basis. However, by canting the feed waveguide as shown in Fig. 1, the wavelength in guide, λ_g , remaining constant, the phases of the feeds to the individual radiators of the transverse linear arrays are progressively advanced or delayed which in turn effectively lengthens or shortens the longitudinal wavelength λ'' . This in turn changes the γ angles of the lobes, while their σ angles are unchanged. For example, Equation 2 applied to the inphase function of the feed waveguide becomes, for $n=0$

$$\cos \gamma = \frac{\lambda}{\lambda''} \quad (4)$$

But from the geometry of Fig. 1,

$$\lambda'' = \frac{2s}{1 + \frac{2\lambda_{g1} \sin a}{2\lambda_{g2}}} \quad (5)$$

in which λ_{g1} is the wavelength in the feed waveguide

and λ_{g2} is the wavelength in the linear arrays. When these two wavelengths are equal, Equation 5 reduces to

$$\lambda'' = \frac{2s}{1 + \sin a} \quad (6)$$

Substituting Equation 6 in Equation 4

$$\cos \gamma = \frac{\lambda(1 + \sin a)}{2s} \quad (7)$$

A similar analysis applied to the antiphase function of the feed waveguide will have a similar result. The conclusion is that canting a feed waveguide by a positive or negative angle a affects the lobe γ angle by an amount given by Equation 7.

The complete operation of the antenna can now be understood, referring to Figs. 1 and 7. When, in energizing the antenna, feed waveguide 11 is employed, ground spots 66' and 68' are illuminated by lobes 66 and 68. When feed waveguide 12 is energized the radiation shifts to lobes 67 and 69. Feed waveguide 13 produces lobes 62 and 64, and feed waveguide 14 produces lobes 61 and 63.

What is claimed is:

1. A microwave antenna for an aircraft comprising at least four parallel linear arrays positioned in a plane, said linear arrays being composed of rectangular waveguides provided with microwave radiators at equal intervals, feed waveguide means for applying microwave energy to the ends of alternate ones of said linear arrays at selected equal phase intervals plus a selected equal increment, feed waveguide means for applying microwave energy to the ends of the remaining ones of said linear arrays at said selected equal phase intervals minus said selected equal increment, and microwave switches connected to all said feed waveguide means for selectively applying microwave energy thereto.

2. A microwave antenna for an aircraft comprising, at least four parallel linear arrays composed of rectangular waveguides having microwave radiators positioned thereon at equal intervals along said waveguide, a plurality of feed waveguides positioned substantially in the plane of said arrays, the average direction of said feed waveguides being perpendicular to the common direction of said linear arrays, one half of said plurality of feed waveguides being connected to alternate ones of said linear arrays at equal spacings corresponding to selected equal phase intervals plus a selected equal phase increment and the remainder of said plurality of feed waveguides being connected to the remainder of said linear arrays at said equal spacings corresponding to said selected equal phase intervals minus said selected equal phase increment, and microwave switches connected to said plurality of feed waveguides for selectively applying microwave energy thereto.

3. A microwave antenna for an aircraft comprising, at least four parallel inphase linear arrays in a plane consisting of rectangular waveguides provided with microwave radiating means positioned at such regular intervals that at a selected energizing frequency a single principal lobe of radiation will be radiated in direction away from the feed ends of said linear arrays, a first plurality of feed waveguides feeding both ends of alternate ones of said linear arrays, a second plurality of feed waveguides feeding both ends of the remaining said linear arrays, and microwave switches controlling the alternate applications of microwave power to said first and second pluralities of feed waveguides and to one and the other ends of said linear arrays.

4. A microwave antenna for an aircraft comprising, at least four parallel inphase travelling wave linear arrays in a plane, the radiators thereof being spaced at feed phase intervals of

$$\frac{\pi}{2}$$

radians for the emission of inphase radiation having the same intervals, a first plurality of feed waveguides connected to the ends of alternate linear arrays at intervals corresponding to equal feed phase differences of π radians plus a selected phase increment, a second plurality of feed waveguides connected to the ends of the remaining linear arrays at intervals corresponding to said equal feed phase differences of π radians minus said selected phase increment, and microwave switches selecting said first or second plurality of feed waveguides.

5. A microwave antenna for an aircraft comprising, at least four linear arrays in a plane, a first feed waveguide connected to one end of each of alternate linear arrays, a second feed waveguide connected to the other end of each of said alternate linear arrays, a third feed waveguide connected to one end of each of the remaining linear arrays, a fourth feed waveguide connected to the other end of each of the remaining linear arrays, and microwave switch means having four positions, each position of said microwave switch means connecting a respective one of said four feed waveguides to a source of microwave energy and simultaneously connecting the remaining three feed waveguides to respective absorptive matching impedances.

6. A microwave antenna for an aircraft comprising, at least four linear arrays in a plane, a first feed waveguide connected to one end of each of alternate linear arrays, a second feed waveguide connected to the other end of each of said alternate linear arrays, a third feed waveguide connected to one of each of the remaining linear arrays, a fourth feed waveguide connected to the other end of each of the remaining linear arrays, three microwave switches each having two positions, two of said switches being operated in concert, whereby combined operation provides four positions, each of said switches containing an absorptive matching microwave impedance, means connecting said four feed waveguides to the two of said switches operated in concert, means connecting said two switches to the third switch, and a source of microwave energy connected to said third switch whereby in each of said four positions a respective one of said four feed waveguides is connected to said source while the remaining three feed waveguides are connected respectively to said impedances.

7. A microwave antenna for an aircraft comprising, at least four linear arrays in a plane, a first feed waveguide connected to one end of each of alternate linear arrays, a second feed waveguide connected to the other end of each of said alternate linear arrays, a third feed waveguide connected to one end of each of the remaining linear arrays, a fourth feed waveguide connected to the other end of each of the remaining linear arrays, two two-position microwave switches each having two output terminals, one input terminal and an absorptive matching impedance, means connecting each of said four feed waveguides to one of the output terminals of said two microwave switches, a single two-position microwave switch having two output terminals, one power input terminal and an absorptive matching impedance, means connecting the two output terminals of said single microwave switch to the two input terminals of said two microwave switches, a source of microwave energy connected to said power input terminal, and means operating said two microwave switches in concert between their two positions and said single microwave switch between its two positions whereby in each of the four combined positions a respective one of said four feed waveguides is connected to said source of microwave energy while the other three of the four feed waveguides are connected to respective ones of said switch absorptive matching impedances.

8. A microwave antenna for an aircraft comprising, at least four parallel linear arrays, each said linear array comprising a rectangular waveguide containing equally

spaced equally coupled radiators, said equal spacing representing phase progressions from the feed end of

$$0, -\frac{\pi}{2}, \pi, +\frac{\pi}{2}, \text{etc.}$$

whereby a single inphase principal lobe is radiated, first and second feed waveguides respectively connected to opposite ends of alternate linear arrays, third and fourth feed waveguides respectively connected to opposite ends of the remaining linear arrays, the average of the directions of said four feed waveguides being at right angles to said linear arrays, said first and second feed waveguides being parallel and departing from said average direction by a selected angle, whereby the phase differences of the energies fed to the radiators of the linear arrays are π radians plus a selected increment, said third and fourth feed waveguides being parallel and departing from said average direction by said selected angle but opposite in sense to said departure of the first and second feed waveguides, whereby the phase differences of the energies fed to the radiators of the linear arrays by the third and fourth feed waveguides are π radians minus said selected increment, whereby the four beams emitted by energization of said first and second feed waveguides consist of four lobes, and the same four beams emitted by energization of said third and fourth feed waveguides consist of four other lobes respectively intersecting said four lobes, said eight lobes each individually being frequency compensated with regard to the looking angle in the average direction of said four feed waveguides, and three two-position microwave switch means having four positions in combination, in each position said microwave switch means connecting a respective one of said feed waveguides to a transmitter-receiver and also connecting the three remaining feed waveguides to three absorptive matching impedances respectively.

9. A microwave antenna assembly comprising, at least twelve parallel linear arrays positioned in a plane, each of said linear arrays including a rectangular waveguide having a plurality of radiating elements spaced at equal intervals along its length and arranged symmetrically as respects the longitudinal center of the waveguide with which they are associated, the waveguides which are more remote from the center of the antenna assembly having lesser numbers of radiating elements whereby the radiating elements of the entire antenna assembly occupy an area substantially circular in form, a first feed waveguide connected to one end of each of alternate linear arrays, a second feed waveguide connected to the other end of each of said alternate linear arrays, a third feed waveguide connected to one end of each of the remaining linear arrays, a fourth feed waveguide connected to the other end of each of the remaining linear arrays, and microwave switch means having four positions, each position of said microwave switch means connecting a respective one of said four feed waveguides to a source of microwave energy and simultaneously connecting the remaining three feed waveguides to respective absorptive matching impedances.

10. A microwave antenna assembly comprising, at least twelve parallel linear arrays positioned in a plane, each of said linear arrays including a rectangular waveguide having a plurality of radiating elements spaced at equal intervals along its length and arranged symmetrically as respects the longitudinal center of the waveguide with which they are associated, the waveguides which are more remote from the center of the antenna assembly having lesser numbers of radiating elements whereby the radiating elements of the entire antenna assembly occupy an area substantially circular in form, a first feed waveguide connected to one end of each of alternate linear arrays, a second feed waveguide connected to the other end of each of said alternate linear arrays, a third feed waveguide connected to one of each of the remaining linear arrays, a fourth feed waveguide

connected to the other end of each of the remaining linear arrays, three microwave switches each having two positions, two of said switches being operated in concert, whereby combined operation provides four positions, each of said switches containing an absorptive matching microwave impedance, means connecting said four feed waveguides to the two of said switches operated in concert, means connecting said two switches to the third switch, and a source of microwave energy connected to said third switch whereby in each of said four positions a respective one of said four feed waveguides is connected to said source while the remaining three feed waveguides are connected respectively to said impedance.

11. A microwave antenna assembly comprising, at least twelve parallel linear arrays positioned in a plane, each of said linear arrays including a rectangular waveguide having a plurality of radiating elements spaced at equal intervals along its length and arranged symmetrically as respects the longitudinal center of the waveguide with which they are associated, the waveguides which are more remote from the center of the antenna assembly having lesser numbers of radiating elements whereby the radiating elements of the entire antenna assembly occupy an area substantially circular in form, a first feed waveguide connected to one end of each of alternate linear arrays, a second feed waveguide connected to the other end of each of said alternate linear arrays, a third feed waveguide connected to one end of each of the remaining linear arrays, a fourth feed waveguide connected to the other end of each of the remaining linear arrays, two two-position microwave switches each having two output terminals, one input terminal and an absorptive matching impedance, means connecting each of said four feed waveguides to one of the output terminals of said two microwave switches, a single two-position microwave switch having two output terminals, one power input terminal and an absorptive matching impedance, means connecting the two output terminals of said single microwave switch to the two input terminals of said two microwave switches, a source of microwave energy connected to said power input terminal, and means operating said two microwave switches in concert between their two positions and said single microwave switch between its two positions whereby in each of the four combined positions a respective one of said four feed waveguides is connected to said source of microwave energy while the other three of the four feed waveguides are connected to respective ones of said switch absorptive matching impedances.

12. A microwave antenna assembly comprising, at

least twelve parallel inphase linear arrays positioned in a plane, each of said linear arrays including a rectangular waveguide having a plurality of radiating elements spaced at feed phase intervals of

$$\frac{\pi}{2}$$

radians along its length and arranged symmetrically as respects the longitudinal center of the waveguide with which they are associated, the waveguides which are more remote from the center of the assembly having lesser numbers of radiating elements whereby the radiating elements of the entire antenna assembly occupy an area substantially circular in form, first and second feed waveguides respectively connected to opposite ends of alternate linear arrays, third and fourth feed waveguides respectively connected to opposite ends of the remaining linear arrays, the average of the directions of said four feed waveguides being at right angles to said linear arrays, said first and second feed waveguides being parallel and departing from said average direction by a selected angle, whereby the phase differences of the energies fed to the radiators of the linear arrays are π radians plus a selected increment, said third and fourth feed waveguides being parallel and departing from said average direction by said selected angle but opposite in sense to said departure of the first and second feed waveguides, whereby the phase differences of the energies fed to the radiators of the linear arrays by the third and fourth feed waveguides are π radians minus said selected increment, whereby the four beams emitted by energization of said first and second feed waveguides consist of four lobes, and the same four beams emitted by energization of said third and fourth feed waveguides consist of four other lobes respectively intersecting said four lobes, said eight lobes each individually being frequency compensated with regard to the looking angle in the average direction of said four feed waveguides, and three two-position microwave switch means having four positions in combination, in each position said microwave switch means connecting a respective one of said feed waveguides to a transmitter-receiver and also connecting the three remaining feed waveguides to three absorptive matching impedances respectively.

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