

June 7, 1960

G. STAVIS ET AL
MICROWAVE ANTENNA

2,940,075

Filed Jan. 16, 1957

4 Sheets-Sheet 1

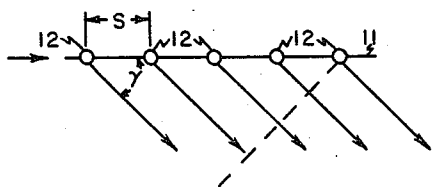


Fig. 1

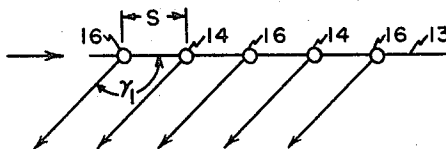


Fig. 2

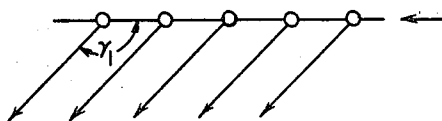


Fig. 9

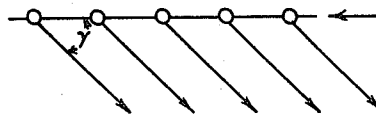


Fig. 10

0	$-\frac{\pi}{2}$	π	$\frac{\pi}{2}$	0	$-\frac{\pi}{2}$
$-\frac{\pi}{2}$	π	$\frac{\pi}{2}$	0	$-\frac{\pi}{2}$	π
π	$\frac{\pi}{2}$	0	$-\frac{\pi}{2}$	π	$\frac{\pi}{2}$
$\frac{\pi}{2}$	0	$-\frac{\pi}{2}$	π	$\frac{\pi}{2}$	0

Fig. 4

0	$\frac{\pi}{2}$	π	$-\frac{\pi}{2}$	0	$\frac{\pi}{2}$
$\frac{\pi}{2}$	π	$-\frac{\pi}{2}$	0	$\frac{\pi}{2}$	π
π	$-\frac{\pi}{2}$	0	$\frac{\pi}{2}$	π	$-\frac{\pi}{2}$
$-\frac{\pi}{2}$	0	$\frac{\pi}{2}$	π	$-\frac{\pi}{2}$	0

Fig. 5

0	S'	π	0
π		0	π
π		0	π
0		π	0

Fig. 6

0	π	0
0	π	0
π	0	π
π	0	π

Fig. 7

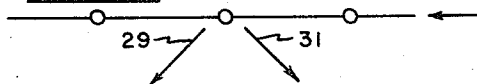


Fig. 11

INVENTOR.
GUS STAVIS
HENRY SALTZMAN
JOHN F. ZALESKI
BY
H. S. Mackay
ATTORNEY

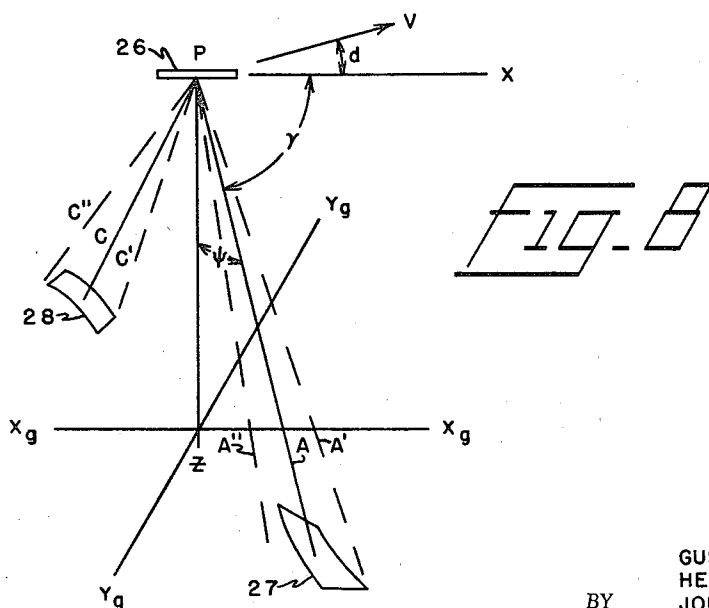
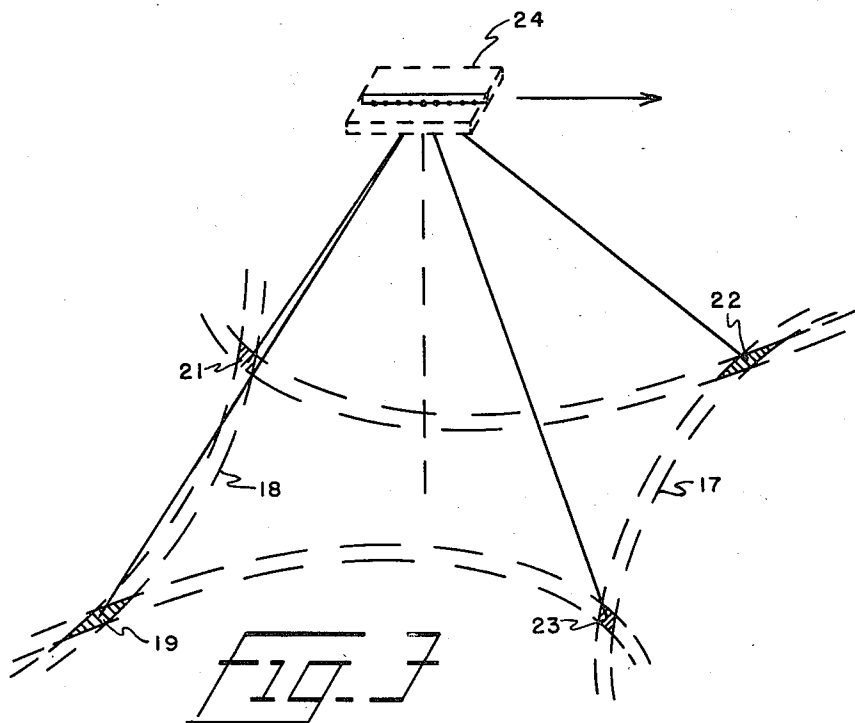
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INVENTORS
GUS STAVIS
HENRY SALTZMAN
JOHN F. ZALESKI
BY
H. S. Mackay
ATTORNEY

June 7, 1960

G. STAVIS ET AL
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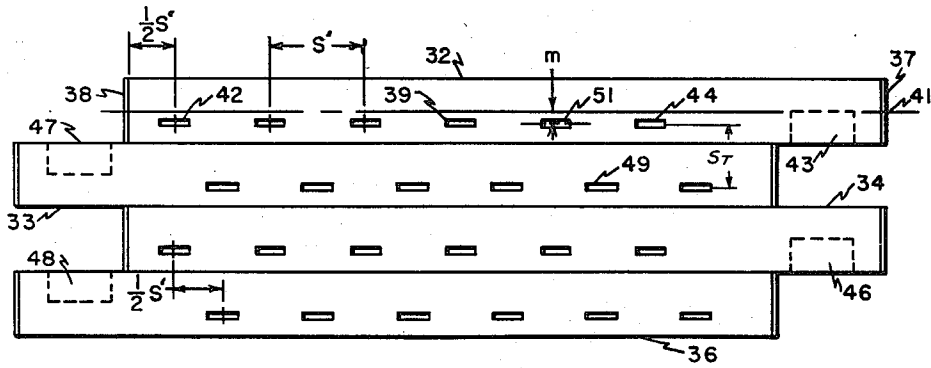


FIG. 13

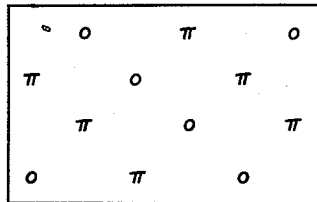


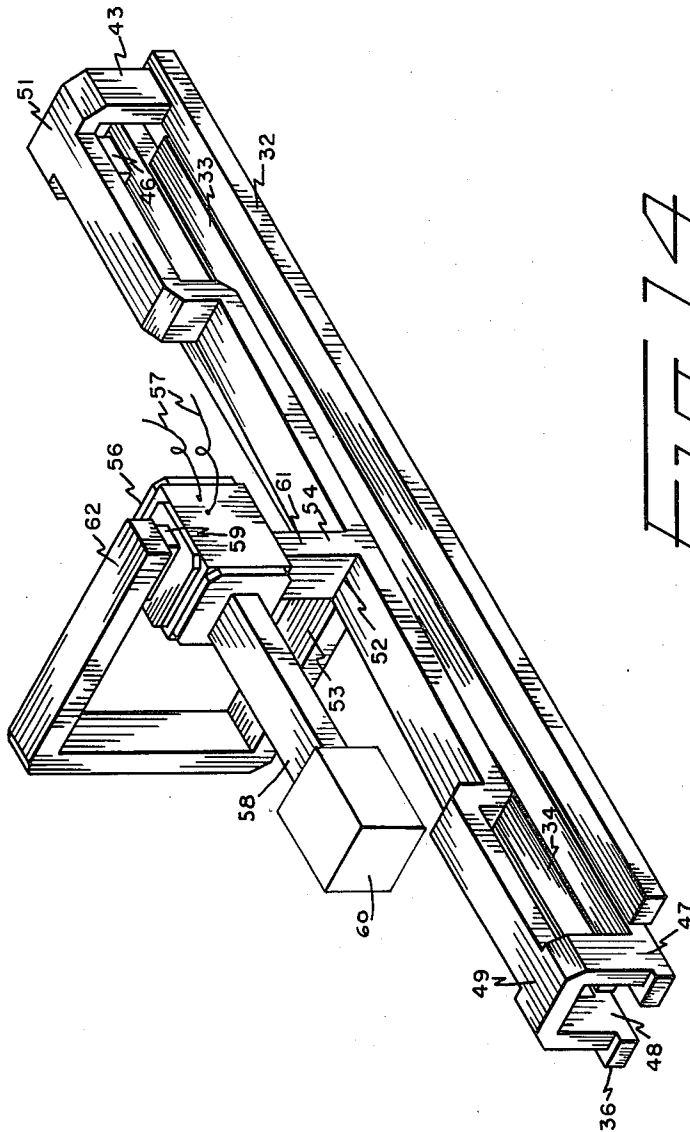
FIG. 12

INVENTOR.
GUS STAVIS
HENRY SALTZMAN
JOHN F. ZALESKI
BY
H. S. M. [Signature]
ATTORNEY

G. STAVIS ET AL
MICROWAVE ANTENNA

Filed Jan. 16, 1957

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GUS STAVIS
HENRY SALTZMAN
JOHN F. ZALESKI

BY

ATTORNEY

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2,940,075

MICROWAVE ANTENNA

Gus Stavits, Ossining, Henry Saltzman, White Plains, and John F. Zaleski, Valhalla, N.Y., assignors to General Precision, Inc., a corporation of Delaware

Filed Jan. 16, 1957, Ser. No. 634,581

10 Claims. (Cl. 343-100)

This invention relates to antennas for Doppler microwave apparatus and particularly to such antennas for use in airborne navigational equipment.

The antenna of this invention is useful when aircraft ground speed and drift angle are to be measured. The novelty of this invention resides in the substantial independence of the horizontal signal outputs of any aberrations in the exciting microwave frequency even when the aircraft is diving or climbing.

This antenna is particularly adapted for use in any ground speed and drift measuring system in which a pair of microwave beams is directed toward the earth, one beam forward and to one side of the antenna's longitudinal axis, and the other rearward and to the other side of the axis. The echo signals from the pair of beams are received and beat together to derive sum or difference frequency signals, from which by appropriate instrumentation, which is not a part of this invention, the above output indications are secured.

In general, this antenna is similar to the planar microwave antenna array described in patent application Serial No. 334,914, now Patent No. 2,854,666, issued September 30, 1958. This array emits a first beam forward and to the right of the axis and a second beam to the rear and left. These beams are periodically switched so that the forward beam is to the left of the axis and the rear beam is to the right. The ground speed and drift indications derived from the beam echoes are independent of changes in transmitting frequency when, and only when, the aircraft is neither diving nor climbing. When dive or climb angle does exist any aberration of microwave energizing frequency causes output error.

In the referenced invention this error occurs because departure of the microwave frequency from its nominal value at any time causes simultaneous changes in the directions of the pair of array beams. Either both beams are shifted forward or both are shifted backward. In level flight this causes no change in the Doppler difference frequency derived from intermodulation of the beam echoes, but in diving or climbing flight this does cause an error in the derived Doppler frequency.

The antenna of the instant invention consists of a plurality of linear arrays placed side by side in a horizontal plane. The planar array thus formed is oriented in the aircraft to point in the ground track direction. Alternate linear arrays are fed at one end and the rest are fed at the opposite end. A pair of beams is emitted as described, but each beam is composed of two components, one generated by the arrays fed from one end, and the other by the remaining arrays. When the microwave frequency has its nominal value these two components are combined to form a single narrow beam. However, when the microwave frequency departs from its nominal value one of the components moves slightly forward and the other component moves slightly to the rear, so that the beam's average direction does not change and there is therefore no output signal error produced when the aircraft is diving or climbing.

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One purpose of this invention is to provide an improved microwave planar array antenna.

Another purpose of this invention is to provide a planar array composed of linear arrays, one-half of the arrays being fed from one end and the remainder from the other whereby eight concentrated beams are emitted which in level flight are space-coincident in pairs.

Still another purpose of this invention is to provide an airborne planar array having an output which is independent of frequency aberrations in the presence of vertical velocity.

A further understanding of this invention may be secured from the detailed description and drawings, in which:

Figures 1, 2, 9 and 10 represent single-beam microwave linear arrays.

Figures 3 and 8 are oblique views showing emitted microwave beams.

Figures 4, 5, 6, 7 and 12 are space phase diagrams of planar array antennas.

Figure 11 represents a double-beam microwave linear array showing inphase and antiphase beams of radiation.

Figure 13 is a plan drawing of the face of a planar array embodying the invention.

Figure 14 is an isometric drawing showing the feed arrangements for the planar array antenna of Figure 13.

The antenna of this invention comprises several linear arrays but this description will start with single linear arrays to insure clarity. Referring now to Fig. 1, the line 11 represents a rectangular microwave guide fed at the left end with microwave energy having frequency f and wavelength λ in free space. The wavelength in the waveguide 11 is λ_g . The waveguide is provided with radiators 12 equally spaced by the distance s . The applied energy phases at the radiators are such that the radiated energy is emitted in the direction of the arrows, making an acute angle γ with the waveguide. When all radiators have the same coupling phase the radiation of the zeroth lobe is, as shown, in the direction away from the feed end and at such an angle γ that

$$\cos \gamma = \frac{\lambda}{\lambda_g} \quad (1)$$

Such a linear array is sometimes termed an inphase array, and the beam which it emits may for the purpose of this description be termed an inphase beam.

By "coupling phase" is meant the influence which the coupling of a radiator has on the phase of the radiation at a distance. As an example, if the radiator is a shunt slot in the broad face of the rectangular guide its coupling phase changes by 180° when it is moved from one side of the longitudinal guide axis to the other side.

In Fig. 2 the coupling phases of alternate radiators of the linear array 13 are reversed. That is, the coupling phases of radiators 14 are alike and those of radiators 16 are also alike but of opposite sense to those of radiators 14. Such a linear array is termed an antiphase array. When excited from the left end as shown with appropriate feed phases at the radiators its radiation of the zeroth lobe is in the direction of the arrows toward the exciting end at an obtuse angle γ_1 , and

$$\cos \gamma_1 = \frac{\lambda}{\lambda_g} - \frac{\lambda}{2s} \quad (2)$$

This emitted beam may be termed, for the purpose of this description, an antiphase beam.

In general whether the radiation behaves in accordance with Equation 1 or Equation 2 depends on the coupling of each radiator to its waveguide. For the purposes of this specification a microwave beam is of the inphase or antiphase type depending on whether it in conjunction

with the emitting linear array including its power feed arrangements behaves as described by Equation 1 or as described by Equation 2 respectively. This statement applies to linear arrays but by a redefinition of the spacing term s the statement also applies to the longitudinal and transverse rows of radiators comprising the planar arrays of this invention.

If an inphase and antiphase array be employed in an aircraft and the inphase and antiphase beams directed toward the earth, then if the echoes are beat together the resulting Doppler frequency difference D is independent of changes in the transmitting frequency and

$$D = \frac{V}{\lambda} \quad (3)$$

in which V is the aircraft ground track speed. That is, the Doppler frequency is independent of the microwave frequency and changes in the latter do not affect the accuracy of the Doppler measurement. The inphase and antiphase beams may be generated by a pair of linear arrays as shown in Figs. 1 and 2, or it may be imagined that these two arrays are in some manner combined into a single, two-beam array. Such an array fed from the left end would simultaneously generate an inphase beam toward the right or away from the feed end and an antiphase beam toward the left or toward the feed end.

It is highly desirable in aircraft Doppler microwave apparatus to make the received signal information independent of fortuitous changes in transmitting frequency which can only be avoided with difficulty, and therefore the described combination of inphase and antiphase beams is in wide use. Such beams may be generated by two separate linear arrays as described placed side by side, or by two-beam linear arrays, or most frequently by a planar array which is composed of a plurality of single-beam or two-beam linear arrays.

Each of the linear arrays of Figs. 1 and 2 emits a cone of radiation coaxial with the array axis, and the pair of linear arrays in combination emits a pair of coaxial cones of radiation. The walls of these cones are thinner for long arrays. The intersections of these cones with a plane parallel to the axis are hyperbolic figures, and when a pair of such linear arrays is positioned horizontally in an aircraft with the array axis in the ground track direction the cones of radiation illuminate the earth's surface in areas of hyperbolic shape. This is illustrated in Fig. 3 by the hyperbolic areas 17 and 18.

If a number of such linear arrays be placed side by side to form a planar array, and if their radiators form transverse rows having the same progressions as the longitudinal rows so that the space radiations in the transverse directions resemble the radiations in the longitudinal directions, then additional cones of radiation will be formed at the sides. The energy of the irradiation of the earth at the four intersections of these four cones will be in proportion to their product, and will form four concentrated beams as shown by the irradiated areas 19, 21, 22 and 23. By a staggered arrangement of the transverse rows of radiators two of these irradiated spots, 21 and 23, can be reinforced and the other two, 19 and 22, neutralized and eliminated. By a reversal of the phase of the energy fed to alternate arrays, the spots 19 and 22 are irradiated and spots 21 and 23 are eliminated.

One method of forming a planar array composed of two-beam linear arrays is as follows. Fig. 4 represents the bottom plan view of the space phase progressions of a planar array composed of four linear arrays of six radiators each. Such a planar array would emit a single longitudinal cone and a single transverse cone of radiation, and the single ground spot irradiated would be that indicated at 22, Fig. 3. Although Fig. 4 indicates space or radiation phases and is not dependent upon any specific apparatus, such a space pattern would be produced by

four inphase arrays fed from the left with the excitations of individual radiating elements progressing in phase from left to right and similarly the phases of the feeds progressing from top to bottom so that the transverse beam also is of the inphase type. Such a planar array might be employed to generate a single one of the beams of Fig. 3, such as that irradiating spot 22. The beam at this spot 22 therefore might be termed an inphase beam produced by feeding the planar array 24, constructed in accordance with Fig. 4, at its left end.

Fig. 5 represents the bottom plan view of a planar array which is similar except for the space phase progressions, and if fed from the left so that the coupling phases alternate both horizontally and vertically, the beam might be termed an antiphase beam. If in Fig. 3 the planar array 24 were of the form shown in Fig. 5 the spot 19 would be irradiated. Simultaneous use of the two planar arrays of Figs. 4 and 5 would produce both beams 19 and 22, Fig. 3.

Now let it be imagined that the hypothetical arrays as shown in Figs. 4 and 5 be superimposed one upon the other so that they occupy the same space. Inspection of the space phase symbols discloses that alternate phase symbols both horizontally and vertically are the same except that they have opposite signs, the remaining elements being identical and also having like signs. Therefore in such a composite array the opposed signs will cancel, leaving only the phase symbols of like sign. Such a composite array having such coupling and feed phases as to produce such a pattern should irradiate both the spots 19 and 22, Fig. 3. This is indeed found to be the case, and Fig. 6 depicts the space phase plan of such an array. In this figure the distance s' between radiators is twice the distance s of Figs. 1 to 5. By similar procedure the space phase plan of an array to produce both spots 21 and 23, Fig. 3, is found to be as depicted in Fig. 7, spot 23, Fig. 3, being irradiated by an inphase beam with antiphase lateral progression and spot 21 by an antiphase beam with inphase lateral progression. Inspection shows that by reversal of the space phases of alternate linear arrays in either the array plan of Fig. 6 or that of Fig. 7, these two plans would be made identical. That is to say spots 21 and 23, Fig. 3, or spots 19 and 22, could alternatively be irradiated by switching the phases of a planar array constructed in accordance with Fig. 6 or 7.

As one method of producing such a space phase plan as shown in Fig. 6 or 7, and of conveniently transforming one plan to the other, the planar array may be fed from the left end, alternate linear arrays being paralleled with appropriate phase lags. The feed phase of one of these groups is reversed to transform one space phase plan into the other. This will result, in Fig. 3, in transferring the irradiation from one diagonal pair of spots to the other diagonal pair. The fact remains that spots 22 and 23 are irradiated exclusively by beams having longitudinal inphase progression generated by the theoretical inphase arrays forming parts of the planar array as finally developed, and spots 19 and 21 are irradiated exclusively by beams having longitudinal antiphase progression generated by the theoretical antiphase arrays forming parts of the planar array.

Fig. 8 depicts an aircraft P directly above the center of coordinate axes Z , X_g and Y_g on the surface of the earth. The aircraft is moving with velocity V in the direction V in the XZ plane. It contains a planar antenna 26 of the type of Fig. 7 which transmits beams A and C striking the earth at areas 27 and 28. Beam A makes angles γ and ψ with the X and Z axes and beam C at the design frequency has the same ψ angle as beam A. The aircraft is climbing at an angle d . The "Tanus" method of echo reception is employed, the echoes received from areas 27 and 28 being beat together to form a frequency which is the algebraic difference of their

individual Doppler frequencies, v_A and v_C . This difference is expressed by

$$v_A - v_C = \frac{2V}{\lambda} \left\{ -2 \cos d \left[\sin \frac{1}{2} (\gamma_A + \gamma_C) \sin \frac{1}{2} (\gamma_A - \gamma_C) \right] + 2 \sin d \left[\sin \frac{1}{2} (\psi_A + \psi_C) \sin \frac{1}{2} (\psi_A - \psi_C) \right] \right\} \quad (4)$$

When the climb angle d is zero, $\sin d$ is zero, making the second term zero, and when $\psi_A = \psi_C$ the second term is again reduced to zero. When the climb angle d is zero but the microwave frequency departs from its design value, γ_A and γ_C change in accordance with Equations 1 and 2, which become:

$$\cos \gamma_A = \frac{\lambda}{\lambda_g} \quad (5)$$

and

$$\cos \gamma_C = \frac{\lambda}{\lambda_g} - \frac{\lambda}{s'} \quad (6)$$

These changes in γ_A and γ_C affect the first term of Equation 4 but in such a way that the value of $v_A - v_C$ is not affected at all.

Shown graphically, the change in frequency moves beam A forward or backward, say to position A', and moves beam C in a similar direction to position C', so that the difference of the Doppler returns remains as before.

However, when climb angle d is not zero and there is a frequency error it is obvious from Fig. 8 that the ψ angles of beams A' and C' now are not equal, so that the second term of Equation 4 is not zero, and constitutes an error term. That is to say that the antenna as so far described gives an erroneous output when the microwave frequency departs from its design value in the presence of aircraft vertical velocity.

The planar array of Fig. 6 was described as made of two hypothetical planar arrays, each being composed of linear arrays as shown in Figs. 1 and 2, its inphase beam being directed toward the right and its antiphase beam toward the left. If two linear arrays are employed as shown in Figs. 9 and 10, respectively of the inphase and antiphase types, and fed from the right, the two-beam array formed by combining them, Fig. 11, will emit an inphase beam 29 to the left and an antiphase beam 31 to the right. If now a planar array be made of the linear arrays of Fig. 11 it likewise would be fed from the right and would emit an inphase beam toward the left and an antiphase beam toward the right. A similar conclusion would be reached by employing patterns similar to Figs. 4 and 5 but reversed horizontally. Their combination into a two-beam planar array would have the space phase pattern of Fig. 6 horizontally reversed as shown in Fig. 12.

Inspection shows that the arrays of Figs. 12 and 7 are in fact identical. When the microwave frequency has its nominal value the two space phases formed by feeding the array from the right and from the left do in fact produce identical beams symmetrically directed relative to the vertical direction. However, since change of frequency changes the wavelength in the waveguide, which in turn affects the beam angle, when the feed is from one end that end is the reference for wavelength change and the beam direction is shifted relative to that end. When the feed is from the opposite end the beam direction shift is relative to that opposite end. Thus Figs. 7 and 12 are identical in effect only when the microwave frequency has its nominal value, but their outputs suffer opposite horizontal shifts when the frequency is in error.

If now a planar array be made of these two kinds of

two-beam linear arrays in alternation, one kind fed from the left and the other kind fed from the right, the planar array would emit a combined beam toward the left composed in equal parts of inphase and antiphase beams, all pointing in the same direction at the design microwave frequency, and it would also emit a combined beam toward the right composed in equal parts of antiphase and inphase beams, all pointing in the same direction at the design frequency. If now the microwave transmitter frequency should change, all of the inphase rightward beams and antiphase leftward beams generated by the left-fed linear arrays would move to the right in Fig. 8, to positions A' and C' as before described. However, all of the inphase leftward beams and antiphase rightward beams generated by the right-fed linear arrays would move to the positions A'' and C''. The amounts by which they would move would be such that the average position of beams A' and A'' would not be at the A position, but would differ from it by such amount as to change the frequency of the Doppler information so as to neutralize and nullify the change caused by the microwave transmitter frequency change. In an exactly similar manner the average of beams C' and C'' would differ from the C position by an amount resulting in a Doppler frequency change nullifying the Doppler frequency change caused by the microwave transmitter frequency change.

The same result is arrived at algebraically by writing equations in the form of Equation 4 for the beams A' and C', and again for the beams A'' and C''. It will be found that when the two are averaged to find the average value of $(v_A - v_C)$, the two values of the term $(\psi_A - \psi_C)$ cancel, showing that now substantially no error is caused by frequency shift in the presence of vertical velocity.

It is to be emphasized that any combinations of feed phases and coupling phases in a planar array microwave antenna which will produce the described pattern insensitive to changes of frequency in presence of vertical velocity will accomplish the objects of this invention. The physical form may be various but is limited by requirements of beam direction and thickness both longitudinally and laterally, and by the usual necessity of eliminating any higher order major lobes of radiation. One form which is preferred and which is perhaps the easiest to design and construct is described in connection with Figs. 13 and 14.

Fig. 13 is a bottom view of a planar array composed of four similar linear arrays 32, 33, 34 and 36. Each array is constructed of a length of rectangular waveguide closed at both ends by a metal plate such as plates 37 and 38. Each array is provided with shunt radiating slots 39, all on the same side of the center line 41 of a broad face, with the slot spacing s' equal to one-half wavelength in waveguide at the design frequency. The slots in adjacent linear arrays are displaced by a distance of $\frac{1}{2} s'$. At one end the shorting plate 38 is at a distance of $\frac{1}{2} s'$, or one-quarter wavelength in waveguide, from the nearest slot 42. At the other end, the linear array is fed through a shunt transition 43 which is placed far enough from the nearest array slot 44 to permit higher order modes generated in the transition to die out. The distances m by which the several slots are displaced from the waveguide center line 41 determine the degrees of coupling, and should be varied in accordance with well-known laws to minimize secondary lobe radiation.

The distance between the parallel lines of radiators are all equal and the distance, S_T , is determined by the values chosen for the angle γ and the angle β between the transverse axis of the planar array and the projection of the beam direction on the vertical plane comprehending the transverse axis. It is easily shown that

the half angle σ of the transverse cone of radiation is given by

$$\cos \sigma = \frac{\lambda}{4S_T} \quad (7)$$

from which, by geometric transformation,

$$S_T = \frac{\lambda}{4 \sin \beta \sin \gamma} \quad (8)$$

Although the linear arrays are depicted with but six radiators each, they will in practice be extended as required to secure desired beam narrowness in the γ direction. Similarly the number of linear arrays will be increased to secure beam narrowness in the transverse direction.

In the operation of the linear array of Fig. 13, excitation of each linear array produces a standing wave in its waveguide having feed phases π radians apart at adjacent radiators. Since all radiators have the same coupling phase the space phase of the radiations, being the sum of the feed and coupling phases, will be as shown in Fig. 6, and the entire planar antenna will produce the two beams which at the design frequency will make equal ψ angles with the normal direction as shown in Figure 8. All of the right transitions such as transitions 43 and 46, Fig. 13, are connected in parallel and fed in phase to produce alternately opposite lateral radiator phases, and all of the left transitions such as transitions 47 and 48 are connected in parallel and fed in phase. When the two feeds are themselves so mutually phased that, for example, radiators 44 and 49 have the same phase, then the radiation pattern is that of Fig. 6 and a pair of beams to irradiate spots 19 and 22, Fig. 3, is produced. When, however, either feed is reversed in phase so that radiators 49 and 51, Fig. 13, are alike in phase, then the radiation pattern is that of Fig. 7 and the pair of beams is changed in direction to irradiate spots 21 and 23, Fig. 3.

A simple feed and switching arrangement is depicted in Fig. 14, in which linear arrays 32, 33, 34 and 36 represent the like-numbered arrays of Fig. 13. Transitions 47, 48, 43 and 46, Fig. 14, employ rectangular waveguides terminating at shunt apertures in the linear array waveguides, with suitable matching devices including an iris and the displacement of the feed waveguide by a short distance from the end of the array waveguide. The length and thickness of the iris plate and the displacement distance uniquely determine the match. Two walls of the two waveguides are in a common plane and the shunt slot coupling is 100%.

The transitions 47 and 48 are fed from two arms of a shunt T 49 and the transitions 43 and 46 are similarly fed from two arms of a similar shunt T 51. These shunt T's contain improved iris and septum impedance-matching arrangements which are fully described in patent application Serial No. 490,802 of John F. Zaleski now Patent No. 2,848,689 issued Aug. 19, 1958. In each of these shunt T's 49 and 51 the two outputs have the same phase, but because the two output arms bend downward, one with a clockwise bend and the other with a counter-clockwise bend, the phases become reversed and as applied to the linear arrays are opposite. Thus the feed phases to waveguides 33 and 36 are opposite, and the feed phases to waveguides 32 and 34 are opposite, as required by the space phase plans Figs. 6 and 7.

Each of the shunt T's 49 and 51 is connected to a collinear arm of a magic tee hybrid junction 52 by lengths of rectangular guide and two truncated right-angle bends. It is necessary that this structure be symmetrical so that the length of path from the center of magic tee 52 to the first radiator of either array 33 or 36 be the same as the path from magic tee 52 to the first radiator of either array 32 or 34.

The magic tee 52 is provided with improved button and

septum matching arrangements which are fully described in Patent No. 2,689,942, by John F. Zaleski.

The magic tee shunt and series arms 53 and 54 are connected to the two output arms of an electromagnetic microwave switch 56. This switch is operated from a direct-current switch control circuit through conductors 57, and switches microwave energy applied from the microwave generator source 60 through rectangular waveguide 58 either to output waveguide 59 or output waveguide 61 without causing impedance discontinuity during the switching operation. This switch is fully described in Patent No. 2,690,539 by John F. Zaleski.

The transition from switch arm 59 to rectangular waveguide 62 involves both a change of direction and a rotation of the electric field, effected by a diagonal rod inserted through the middle of the transition which at the same time completely impedance-matches the device. This is fully described in Patent No. 2,754,483 of John F. Zaleski.

In the operation of this feed system, when switch 56 switches microwave energy into the shunt arm 53 of magic tee 52, the energy is in phase in the collinear arms and arrives at the first radiators of waveguide arrays 33 and 36 in the same phases as it arrives at the first radiators of waveguide arrays 32 and 34. The radiation pattern is then that of Fig. 6. When, however, switch 56 switches microwave energy into the series arm 54 of magic tee 52, the energy is antiphase in the collinear arms and arrives at the first radiators of waveguide arrays 33 and 36 in phases which are the reverse of the first case. The radiation pattern is then that of Fig. 7.

Thus, in one position of switch 56 the ground spots 21 and 23, Fig. 3, are irradiated, and in the other position of the switch the other spots 19 and 22 are irradiated. In either case each spot is always irradiated by equal energies of inphase and antiphase beams of radiation. When the microwave frequency has its nominal value these two beams are completely superimposed so that a single spot of minimum area is irradiated. However, when any error exists in the frequency these two components, one inphase and one antiphase, spread apart so that the irradiated spot is enlarged. When the spot is so enlarged its effective center differs from the center of the small spot by an amount neutralizing microwave frequency shift error, even during dive or climb of the aircraft.

What is claimed is:

1. A planar microwave antenna array adapted for use in a mobile aircraft having at least one component of velocity extending in a vertical direction, said array being free from transmitting frequency variation error in the presence of vertical velocity comprising, a plurality of linear arrays positioned parallel to each other in a plane, each array comprising a plurality of radiators having relative phases of emission of radiations varying in space phase between successive radiators by π radians, half of said linear arrays forming a first set and the remainder a second set, means feeding microwave energy of a selected frequency and a selected phase to the same ends of all linear arrays of said first set, means interposed in the feed ends of alternate linear arrays of said first set reversing the phases of energy fed to said alternate arrays, means simultaneously feeding microwave energy of said same selected frequency and said same selected phase to the ends of all linear arrays of said second set which are opposite to the feed ends of said first set, and means interposed in alternate ones of the feed ends of said second set reversing the phases of energy fed to said alternate arrays, whereby the entire planar array emits a first inphase and first antiphase beam both in the same direction and a second inphase and second antiphase beam both in a second direction so that changes in each direction caused by transmitting frequency variation in the presence of vertical velocity are nullified.

2. A planar microwave antenna array in accordance

with claim 1 in which phase-reversing means is connected periodically to reverse the phase of the means simultaneously feeding said second set of linear arrays, whereby the separate directions of said beams are periodically switched to two other directions.

3. A planar microwave antenna array adapted for use in a mobile aircraft having at least one component of velocity extending in a vertical direction, said array being free from transmitting frequency variation error in the presence of vertical velocity comprising, a plurality of linear arrays positioned parallel to each other in a plane, each array comprising a plurality of radiators, said radiators being equally spaced and emitting radiations varying from radiator to radiator along each linear array in space phase by π radians, said radiators being equally spaced in columns perpendicular to the longitudinal direction of said linear array and each column emitting radiations varying from radiator to radiator in space phase by π radians, the radiators of each linear array being offset in the longitudinal direction with respect to the radiators of each linear array immediately adjacent thereto, alternate linear arrays forming a first set and the remaining arrays forming a second set, means feeding microwave energy of a selected frequency and a selected phase to the same ends of all linear arrays of said first set, means interposed in the feed ends of alternate linear arrays of said first set reversing the phases of energy fed thereto, means simultaneously feeding microwave energy of said same selected frequency and said same selected phase to the ends of all linear arrays of said second set which are opposite to the feed ends of said first set, and means interposed in alternate ones of the feed ends of said second set reversing the phases of energy fed thereto, whereby the entire planar array emits a first inphase and first antiphase beam both in the same direction and a second inphase and second antiphase beam both in a second direction so that changes in each direction caused by transmitting frequency variation in the presence of vertical velocity are nullified as a result of the composite character of the beams in each direction.

4. A planar microwave antenna array in accordance with claim 3 in which phase-reversing means is connected periodically to reverse the phase of the means simultaneously feeding said second set of linear arrays, whereby the directions of said two composite beams are periodically switched to two other directions.

5. A planar microwave antenna array adapted for use in a mobile aircraft having at least one component of velocity extending in a vertical direction, said array being free from transmitting frequency error in presence of vertical velocity comprising, a plurality of resonant linear arrays positioned parallel to each other in a plane, each linear array including a plurality of microwave radiators fed by a rectangular waveguide, said radiators being equally spaced along the waveguide by one-half wavelength of the energy in the waveguide and emitting radiations varying from radiator to radiator along each linear array in space phase by π radians, said radiators additionally being equally spaced in columns perpendicular to the linear array longitudinal axis direction by an amount

$$S_T = \frac{\lambda}{4 \sin \beta \sin \gamma}$$

in which λ is the free space wavelength, β is the transverse projected beam angle and γ is the angle from the radiation direction to the planar array longitudinal axis, each said column emitting radiations varying from radiator to radiator along each column in space phase by π radians, the radiators in each linear array being offset in the longitudinal axis direction relative to radiators of each adjacent linear array by one-half of the radiator spacing along the waveguide, alternate linear arrays

forming a first set and the remaining linear arrays forming a second set, means feeding microwave energy of a selected frequency and a selected phase to the same ends of all linear arrays of said first set, means interposed in the feed ends of alternate linear arrays of said first set reversing the phases of energy fed to these arrays, means simultaneously feeding microwave energy of said same selected frequency and said same selected phase to the ends of all linear arrays of said second set which are opposite to the feed ends of said first set, and means interposed in alternate ones of the feed ends of said second set reversing the phases of energy fed thereto, whereby the entire planar array emits a composite first inphase and first antiphase beam both in the same direction and a composite second inphase and second antiphase beam both in the same second direction so that changes in each direction caused by transmitting frequency variation in the presence of vertical velocity are nullified due to the composite character of the beam in each direction.

6. A planar microwave antenna array in accordance with claim 5 in which phase reversing means is connected periodically to reverse the phase of the means simultaneously feeding said second set of linear arrays, whereby the directions of said two composite beams are periodically switched to two other directions.

7. A planar microwave antenna array adapted for use in a mobile aircraft having at least one component of velocity extending in a vertical direction, said array being free from transmitting frequency variation error in the presence of vertical velocity comprising, a plurality of resonant linear arrays positioned parallel to each other in a plane, each linear array including a rectangular waveguide, a plurality of radiating elements supported thereon and energized therefrom, all said radiating elements of all linear arrays having the same spacing in the direction of the longitudinal axis of their respective linear arrays, a microwave generator producing a signal at a selected frequency, said spacing equalling one-half wavelength in the waveguide at said selected frequency, all coupling phases of said radiating elements being equally spaced by an amount such that the space phase of radiating element radiation varies from radiator to radiator by π radians, half of said linear arrays forming a first set and the remainder a second set, waveguide coupling means applying the output energy of said microwave generator at a selected phase to the same ends of alternate linear arrays of said first set and to the opposite ends of alternate linear arrays of said second set, and waveguide coupling means applying the output energy of said microwave generator at the phase opposite to said selected phase to the same ends of the remaining linear arrays of said first set and to the opposite ends of the remaining linear arrays of said second set, said energy being simultaneously applied to all of said linear arrays.

8. A planar microwave antenna array in accordance with claim 7 in which phase-reversing means is periodically inserted in the waveguide coupling means connecting all of said second set of linear arrays to said microwave generator whereby the space phases of the radiations of all radiating elements of the second set are periodically and simultaneously switched between two values differing by π radians.

9. A planar microwave antenna array for use in a mobile aircraft having at least one component of velocity extending in a vertical direction, said array radiating two beams simultaneously the frequency difference of which is unaffected by radiated microwave frequency variations in the presence of velocity normal to the planar array comprising a plurality of resonant linear arrays positioned parallel in a plane, each linear array including a rectangular waveguide supporting and energizing a plurality of radiating elements, said radiating elements being spaced along the longitudinal axis of their

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respective waveguides by amounts equalling one-half the wavelength in said waveguide at said selected frequency, all of said radiating elements having the same coupling phase, whereby the space phases of radiating element radiations vary progressively from radiating element to radiating element by π radians, said radiating elements additionally being equally spaced in columns perpendicular to the linear array longitudinal axis direction by an amount

$$S_T = \frac{\lambda}{4 \sin \beta \sin \gamma}$$

in which λ is the free space wavelength β is the transverse projected beam angle and γ is the angle from the beam direction to said longitudinal axis, the radiating element space phases of radiation varying in each said column from radiating element to radiating element by π radians, the radiating elements in each linear array being offset in the longitudinal axis direction relative to the radiating elements of each adjacent linear array by one-half of said equal linear array spacings, alternate linear arrays forming a first set and the remaining linear arrays forming a second set, a microwave generator producing an output signal at a selected frequency, waveguide coupling means applying the output energy of said microwave generator at a selected phase to the ends of alternate

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arrays of said first set adjacent one side of said planar array and to the ends of alternate linear arrays of said second set adjacent the opposite side of said planar array, and waveguide coupling means applying the output energy of said microwave generator at the phase opposite to said selected phase to the ends of the remaining linear arrays of said first set adjacent said one side of the planar array and to the ends of the remaining linear arrays of said second set adjacent said opposite side of the planar array, the energy being simultaneously applied to all of said linear arrays.

10. A planar microwave antenna array in accordance with claim 9 in which phase-reversing means is periodically inserted in the waveguide coupling means connecting all of said second set linear arrays to said microwave generator whereby the space phase of the radiations of all radiating elements of the second set are periodically and simultaneously switched between the same two values differing by π radians.

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