Sept. 1, 1970 T. E. PLUNK ET AL 3,526,898

ANTENNA WITH TRANSLATIONAL AND ROTATIONAL COMPENSATION

Filed April 3, 1967

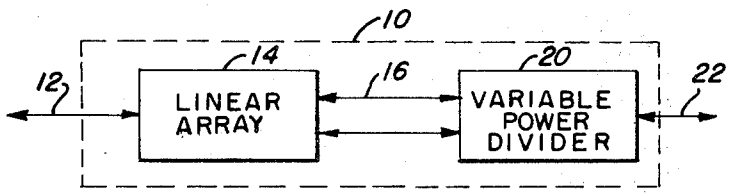


FIG. 1

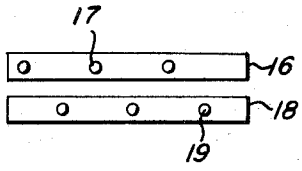


FIG. 4

FIG. 2

FIG. 3

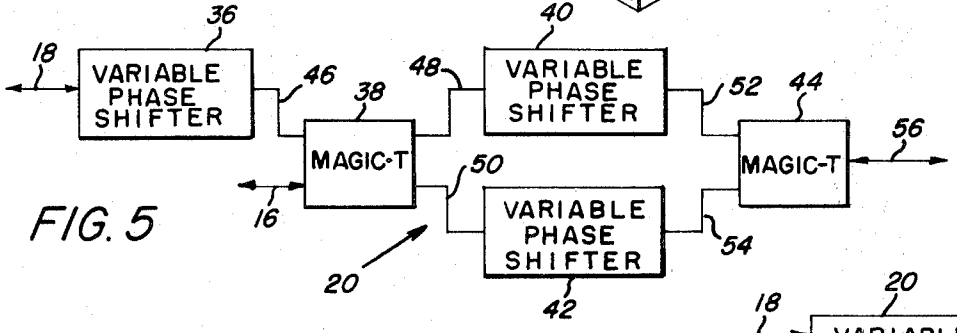


FIG. 5

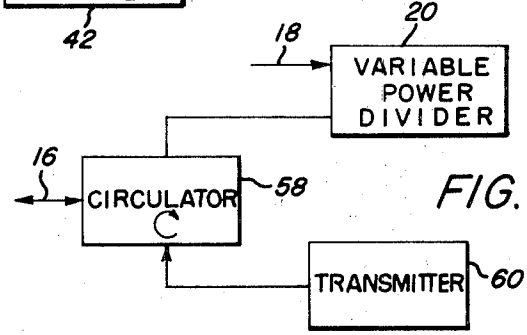


FIG. 6

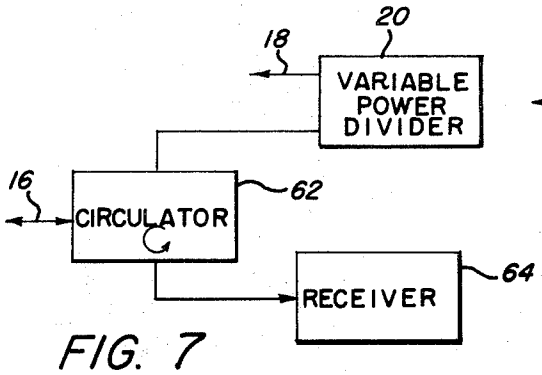


FIG. 7

INVENTORS
TROY E. PLUNK
NATHAN SLAWSBY

BY Carole M. Calman
ATTORNEY

United States Patent Office 3,526,898
Patented Sept. 1, 1970

3,526,898

ANTENNA WITH TRANSLATIONAL AND ROTATIONAL COMPENSATION

Troy E. Plunk, Bedford, and Nathan Slawsby, Canton, Mass., assignors to Raytheon Company, Lexington, Mass., a corporation of Delaware

Filed Apr. 3, 1967, Ser. No. 628,081
Int. Cl. H01q 13/10, 13/00
U.S. Cl. 343—771 6 Claims

ABSTRACT OF THE DISCLOSURE

An antenna for a radar system comprising a linear phased array having two different edge slotted linear arrays which are interleaved, and a variable power divider which varies the phase and amplitude of the drive power to the arrays.

BACKGROUND OF THE INVENTION

Field of the invention

The invention pertains to moving radar systems such as groundborne, seaborne, or airborne systems.

Description of the prior art

One previous technique processes the sum and difference patterns from phase and amplitude monopulse systems in the receiver at intermediate frequency in order to provide compensation. However, this compensation is not precise and is not achieved during both transmit and receive.

The prior art describing interleaped planar arrays does not teach arrays which provide compensation.

SUMMARY OF THE INVENTION

An antenna having translational and rotational compensation comprising a linear phased array having two interleaved radiators with one radiator producing a sine illumination function and the other producing a cosine illumination function.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the inventive antenna;

FIG. 2 is a diagrammatic representation of the linear phased array;

FIG. 3 is a diagrammatic representation of a portion of a radiator;

FIG. 4 is a diagrammatic representation of coupling waveguides;

FIG. 5 is a block diagram of a variable power divider;

FIG. 6 is a block diagram showing the operation of the variable power divider when there is compensation for receive only; and

FIG. 7 is a block diagram showing the operation of the variable power divider when there is compensation for transmit only.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A block diagram of the inventive antenna **10** is shown in FIG. 1 and comprises linear phased array **14** connected to variable power divider **20**. During receive operation, a target echo is received on line **12** and passes into linear phased array **14**. The signals produced by linear phased array **14** are passed to variable power divider **20** via lines **16** and **18**. However, during transmit operation, variable power divider **20** applies signals to the waveguides represented by lines **16** and **18** which then enter linear phased array **14**. Linear phased array **14** then transmits signals into space via line **12**.

Antenna **10** produces translational displacement of the phase center of linear phased array **14** and simultaneously rotates the far field antenna pattern through small angles. The far field antenna pattern may be represented by the following equation:

$$\frac{\cos^2 u}{\left(\frac{\pi}{2}\right)^2 - u^2} \tag{1}$$

where

$u = \pi d/\lambda \sin\theta$

d = the length of the linear arrays

θ = the angle measured from a perpendicular to the face of the array and in the plane of the long dimension

Such an antenna has wide application in the field of airborne radars where it is desirable to compensate for the forward motion of the platform or aircraft, and the rotation of the antenna while scanning. The translational displacement of the phase center of linear phased array **14** gives the effect of lifting antenna **10** and sliding it over. The phase center of linear phased array **14** is the point about which there is a constant phase at a constant radius. The rotation of the far field antenna pattern gives the effect of physically rotating antenna **10**.

Linear phased array **14** is diagrammatically shown in FIG. 2 and comprises two different linear arrays **24** and **26** which are interleaved and selectively coupled to coupling waveguides **16** and **18** shown in detail in FIG. 4. Linear array **24** produces a cosine illumination function, while linear array **26** produces a sine illumination function. Accordingly, the amplitude and phase magnitude of energy generated by array **24** is in the form of a cosine waveform, whereas the energy generated by array **26** is in the form of a sine waveform. By varying the phase and amplitude of the drive power to each array **24** and **26** using variable power divider **20** which will be described in detail later, it is possible to compensate for the forward motion of a platform and antenna rotation.

In order to best describe the inventive antenna **10**, a physical description thereof is being given first and will be followed by its mathematical analogy. Linear phased array **14** comprises a set of stacked, edge slotted linear radiators wherein every other radiator **24** has a cosine illumination function, and the intervening radiators **26** have a sine illumination function. These current distributions are obtained by selectively varying the angle of inclination of the slots **28**, which is a well-known technique. For example, it is described in "Massachusetts Institute of Technology Radiation Laboratory Series," published by McGraw-Hill Book Company Inc., 1949, Volume 12, chapter 9, wherein it is shown that an edge slot in the narrow wall of a rectangular waveguide (for example, FIG. 9.17(e) of the referenced text) can be represented by a simple shunt equivalent circuit having a conductance g given by the relationship

$$g = \frac{30}{73\pi}\left(\frac{\lambda_g}{\lambda}\right)\frac{\lambda^4}{a^3 b}\left[\frac{\sin\theta\cos\left[\left(\frac{\pi\lambda}{2\lambda g}\right)\sin\theta\right]}{1-\left(\frac{\lambda}{\lambda_g}\right)^2\sin^2\theta}\right]^2$$

in which λ and λ_g are respectively the free space and guide wavelengths of the radiation, a and b are respectively the broad and narrow wall widths, and θ is the angle of inclination of a slot (θ=0 corresponding to a slot perpendicular to the edge of the waveguide). The power radiated from such a slot is proportional to the conductance g and accordingly, the power and the magnitude of the electric field radiated from each of a series of such slots is selected by choosing the slot angle

θ from the foregoing equation, that is incorporated herein by reference. FIG. 3 depicts a portion of a sample radiator **30** having slots **28** shown in more detail. Radiator **30** comprises a waveguide, and slots **28** are rectangular in shape. Nevertheless, other shapes may be used in order to achieve the desired illumination function. Slots **28** are cut into side **32** of radiator **30** and extend the whole width of side **32**. There are no slots in the other sides of radiator **30**.

In FIG. 2, lines **16** and **18** represent waveguides, and lines **17** and **19** represent holes therein. These waveguides are shown in detail in FIG. 4, and would be arranged parallel to each other and each being flush with ends **34** of linear arrays **24** and **26**. Waveguide **16** affords coupling for linear arrays **24** which generate a cosine illumination function. Each hole **17** is arranged to be positioned at end **34** of one linear array **24** in order to provide the coupling thereto. Similarly, waveguide **18** affords coupling for linear arrays **26** which generate a sine illumination function. Every hole **19** is arranged to be positioned at end **34** of one linear array **26** to provide the coupling thereto. Hence, waveguides **16** and **18** are located perpendicular to linear arrays **24** and **26**.

Variable power divider **20** is depicted in FIG. 5 and comprises variable phase shifter **36** connected to waveguide magic-T **38**; waveguide magic-T **44**; and, variable phase shifters **40** and **42** connected between magic-T **38** and magic-T **44**. Variable phase shifters **36**, **40**, and **42** may comprise ferrite digital latching phase shifters. The phase and amplitude of the power fed to linear phased array **14** is supplied by variable power divider **20** and particularly by variable phase shifters **36**, **40**, and **42**. Magic-T **38** is of conventional form and as is well known, signals entering the pair of arms **48** and **50**, in phase, exit through the sum arm (H plane arm), while signals entering the pair of arms **48** and **50**, antiphased, exit through the difference arm (E plane arm). At intermediate phase relationships, the sum of these two signals splits between the sum and difference arms. Thus, the power entering magic-T **38** via arms **48** and **50** is divided between the arms **16** and **46** in accordance with the relative phase shifts applied by the variable phase shifters **40** and **42**. Variable phase shifter **36** provides the desired phase shift between signals entering linear arrays **24** and **26**. During receive operation, waveguide **18** which is coupled to linear array **26** receives sine illumination energy and applies it to variable phase shifter **36** that shifts its phase before applying the energy to magic-T **38** via line **46**. In addition, waveguide **16** which is coupled to linear array **24** applies cosine illumination energy to magic-T **38**. Magic-T **38** couples the sine illumination energy from variable phase shifter **36** to variable phase shifter **42**, and the cosine illumination energy from waveguide **16** to variable phase shifter **40**. Variable phase shifter **40** shifts the phase of the cosine illumination energy and applies the energy to magic-T **44**, while variable phase shifter **42** shifts the phase of the sine illumination energy and applies the energy to magic-T **44** which then couples the energy to a receiver (not shown).

During transmit operation, variable power divider **20** operates in the opposite direction in order to couple energy to cosine linear array **24** and sine linear array **26** from a transmitter (not shown). Magic-T **44** selectively applies energy to variable phase shifters **40** and **42** which shift the phase of their input energy. The energy from variable phase shifter **40** and variable phase shifter **42** is next applied to magic-T **38** which selectively applies energy to variable phase shifter **36** and to waveguide **16** that is coupled to cosine linear arrays **24**. Variable phase shifter **36** shifts the phase of the received energy and applies the energy to waveguide **18** which is coupled to sine linear arrays **26**. Although one embodiment of variable power divider **20** has been described, it should be appreciated that other embodiments are possible.

In the foregoing description, compensation for the forward motion of a platform and antenna rotation was performed during both receive and transmit operations. However, it is also possible to compensate only during receive or only during transmit operation. FIG. 6 depicts the operation of variable power divider **20** when there is compensation for receive only. Hence, during receive operation, waveguide **18** which is coupled to sine linear arrays **26** applies energy to variable power divider **20**. Waveguide **16** which is coupled to cosine linear arrays **24** applies energy to circulator **58** that may be a ferrite circulator and that in turn transfers this energy to variable power divider **20**. Upon transmit operation, transmitter **60** transmits energy to circulator **58** which then applies it to waveguide **16**. Since waveguide **16** is coupled to linear arrays **24**, only the cosine linear arrays **24** receive energy during transmit operation.

FIG. 7 depicts the operation of variable power divider **20** when there is compensation for transmit only. Thus, during receive operation, waveguide **16** which is coupled to linear array **24** applies cosine energy through circulator **62** to receiver **64**. Consequently, receiver **64** obtains only cosine energy during receive operation. Upon transmit operation, variable power divider **20** applies energy to waveguide **18** which is coupled to sine linear arrays **26**. In addition, variable power divider **20** transfers energy to circulator **62** which then applies it to waveguide **16** that is coupled to cosine linear arrays **24**.

As was mentioned previously, linear phased array **14** is compensated in order to cause the electrical phase center to be moved linearly in addition to rotating the far field pattern. This can be easily illustrated mathematically by first considering the total aperture function in the long dimension of the array for the translational case alone. This function is as follows:

$$f(x)=\cos\frac{\pi x}{a}+k_1\sin\frac{\pi x}{a} \tag{2}$$

where:

x=the dimensional variable along the length of array **14**
a=length of array **14**
k_1=a constant which determines the amount of translation

For the case of rotation alone, the total aperture function can be written:

$$f(x)=\cos\frac{\pi x}{a}+jk_2\sin\frac{\pi x}{a} \tag{3}$$

where:

k_2=a constant which is not equal to k_1 and determines the degree of rotation

Equations 2 and 3 may be restated in different form so that for translation

$$f(x)=(1+k_1^2)^{1/2}\cos\left(\frac{\pi x}{a}+\tan^{-1}k_1\right) \tag{4}$$

and for rotation

$$f(x)=\left[(1-k_2^2)^{1/2}\cos^2\frac{\pi x}{a}+k_2^2\right]^{1/2}\exp j\tan^{-1}\left(k_2\tan\frac{\pi x}{a}\right) \tag{5}$$

For small values of k_2 and x, Equation 5 may be approximated by

$$f(x)=\left[(1-k_2^2)\cos^2\frac{\pi x}{a}+k_2^2\right]^{1/2}\exp j\frac{k_2\pi x}{a} \tag{6}$$

In the usual case where translation and rotation are

simultaneously achieved, the effective aperture distribution along the x-axis is given by:

$$f(x)=\cos\frac{\pi x}{a}+k_1\sin\frac{\pi x}{a}+jk_2\sin\frac{\pi x}{a} \quad (7)$$

which is mathematically equivalent to,

$$f(x)=\sqrt{(1+k_1^2)\cos^2\left(\frac{\pi x}{a}+\tan^{-1}k_1\right)+k_2^2\sin^2\frac{\pi x}{a}}$$

$$xe^{j\tan^{-1}\left(\frac{k_2\sin\frac{\pi x}{a}}{\sqrt{1+k_1^2}\cos\left(\frac{\pi x}{a}+\tan^{-1}k_1\right)}\right)}$$

For comparatively small k_1, k_2, and x, Equation 8 can be approximated by,

$$f(x)\approx g(x)=\sqrt{1+k_1^2}\cos\left(\frac{\pi x}{a}+\tan^{-1}k_1\right)\frac{e^{jk_2}}{\sqrt{1+k_1^2}}\frac{\pi x}{a} \quad (9)$$

Since the amplitude of $f(x)$ is small as x approaches $a/2$, the previous approximations (8) and (9) are valid for every allowable x, i.e. $|x|\leq a/2$. Consequently, Equations 7, 8, and 9 for $f(x)$ are defined over $|x|\leq a/2$ and are zero for $|x|>a/2$.

Note that in the case of translation as described by Equation 4 a term, $\tan^{-1}k_1$, has appeared in the cosine portion. This means that the addition of the sine to the cosine illumination merely produces a shift in the origin of the function without changing its shape. In other words, array **14** appears to have physically translated through a small linear displacement equal to

$$\frac{a}{\pi}\tan^{-1}k_1$$

In the case of rotation, it is necessary to utilize the Fourier transform pair relationship between the aperture distribution function and the far field antenna pattern as follows:

$$e(y)=\int_{-\infty}^{+\infty}f(x)\ \exp -j2\pi xy\,dx;\ y=\frac{\sin\theta}{\lambda} \quad (10)$$

where:

λ=the operating wavelength

θ=the angle measured from a perpendicular to the face of the array and in the plane of the long dimension

Substituting the aperture function for the rotational case in this transform relationship:

$$e(y)=\int_{-\infty}^{+\infty}|f(x)|\exp -j2\pi x\left(\frac{k_2}{2a}-y\right)dx \quad (11)$$

Hence, an angular displacement equal to

$$\sin^{-1}\frac{\lambda k_2}{2a}$$

occurs which is equivalent to a small angular displacement or rotational of the far field pattern.

The far field pattern with both translational and rotational compensation is approximately

$$e(y)=\int_{-a/2}^{a/2}g(x)e^{-j2\pi yz}dx \quad (12)$$

or

$$e(y)=\int_{-a/2}^{a/2}\sqrt{1+k_1^2}\cos\left(\frac{\pi x}{a}+\tan^{-1}k_1\right)e^{j\frac{k_2}{\sqrt{1+k_1^2}}\frac{\pi x}{a}}e^{-j2\pi yz}dx \quad (13)$$

the last Equation 13 for the far field pattern provides an aperture translation of $x_0=a/\pi\ \tan^{-1}k_1$ and an angular rotation of

$$\sin^{-1}\left(\frac{\lambda}{2a}\frac{k_2}{\sqrt{1+k_1^2}}\right)$$

Hence, it is possible to control the amount of rotation and translation by varying the constants k_1 and k_2.

As was mentioned previously, the invention which precisely compensates for the displacement of the platform as well as the rotation of the antenna during scanning has application in airborne radar systems such as pulsed doppler radars where it is desirable in order to prevent distributed target, i.e. ground or sea clutter, spectrum broadening. Such compensation is possible on both transmit and receive. Other radar systems such as side looking radars, airborne fire control, shipborne, truck or tank mounted radars may be improved by using this invention.

Although the invention has been described with reference to a preferred embodiment thereof, it should be appreciated that it is not limited thereby. For instance, the interleaved radiators are not limited to those which generate sine and cosine functions and can produce other combinations of plus and minus functions. Hence, the invention must be given the full scope of the following claims.

What we claim is:

1. An antenna system supported by a moving platform and providing compensation for the movement of the platform, the antenna system comprising:

a first array having an odd illumination function;

a second array, interleaved with the first array, and having an even illumination function; and

variable power divider means adapted to receive power from a transmitter, and communicating a portion of the power to the first array and a second portion of the power to the second array to displace the center of the sum of the odd and the even illumination functions.

2. An antenna system supported by a moving platform and providing compensation for the movement of the platform, the antenna system comprising:

a first array adapted to transmit power and having an odd illumination function;

a second array adapted to transmit power, interleaved with the first array, and having an even illumination function; and

variable phase shifting means for varying the phase of power transmitted by the first array relative to the phase of power transmitted by the second array whereby the far field pattern of the antenna system is rotated.

3. An antenna system supported by a moving platform and providing compensation for the movement of the platform, the antenna system comprising:

a first array adapted to transmit power and having an odd illumination function;

a second array adapted to transmit power, interleaved with the first array, and having an even illumination function;

variable phase shifting means connecting with the first array; and

variable power divider means adapted to receive power from a source of power, and communicating a portion of the power through the variable phase shifting means to the first array and a second portion of the power to the second array, whereby there is a displacement of the center of the sum of the odd and the even illumination functions, and whereby the far field antenna pattern of the antenna system is rotated.

4. The antenna system of claim **3** wherein the variable power divider means comprises a first and a second magic-T, and a first and a second variable phase shifter interconnecting the first and the second magic-T to vary the phase of power in one arm of the second magic-T relative to the phase of power in a second arm of the second magic-T.

5. The antenna system of claim **4** wherein the first and the second arrays each comprise edge slotted waveguides.

6. The antenna system of claim 5 wherein the odd illumination function comprises a sine function and the even illumination function comprises a cosine function.

References Cited

UNITED STATES PATENTS

2,932,823	4/1960	Beck et al.	343—771
2,981,944	4/1961	Washburne	343—768 X
3,135,959	6/1964	Moran	343—771 X

HERMAN KARL SAALBACH, Primary Examiner

S. CHATMON, JR., Assistant Examiner

U.S. Cl. X.R.

343—854