June 4, 1968 J. BLASS ET AL 3,387,301

ANTENNA ARRAY EMPLOYING AN AUTOMATIC AVERAGING TECHNIQUE FOR INCREASED RESOLUTION

Filed March 31, 1966 4 Sheets-Sheet 1

FIG. 1.

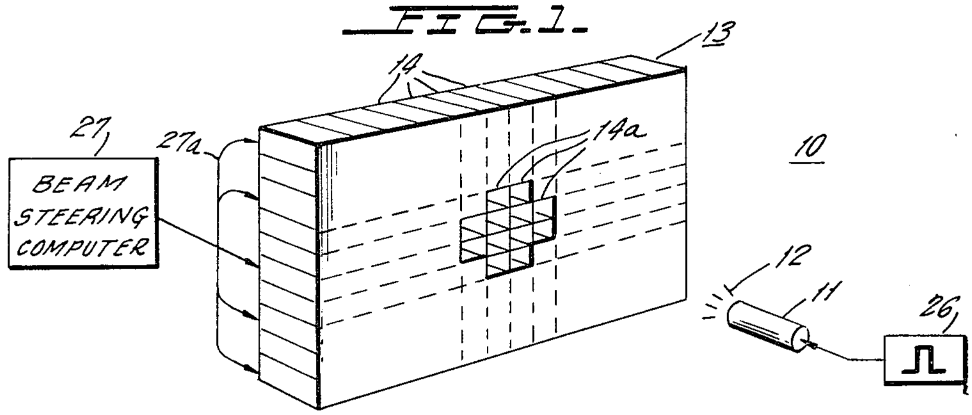


FIG. 1c.

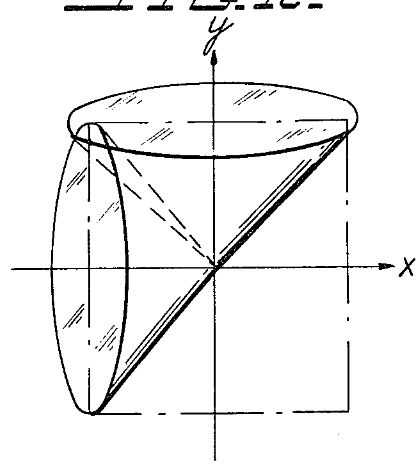
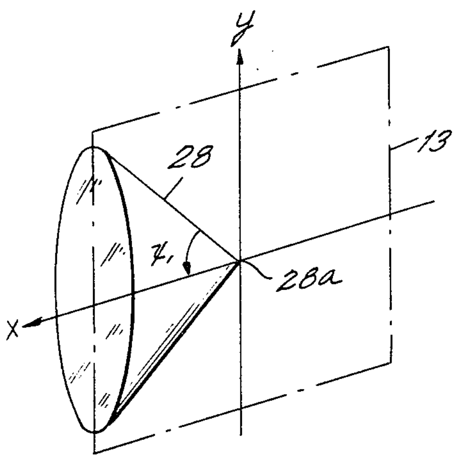


FIG. 1a.



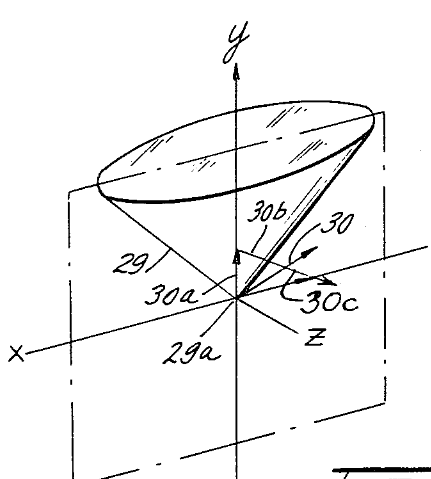


FIG. 1b.

FIG. 2.

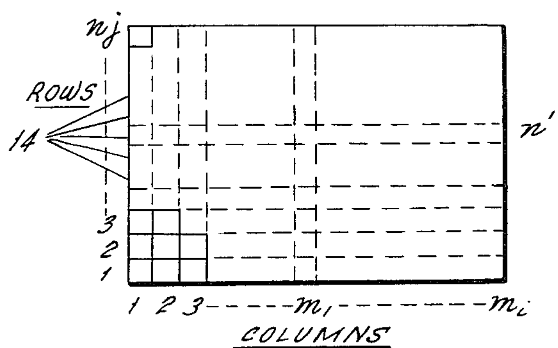


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FIG. 4a

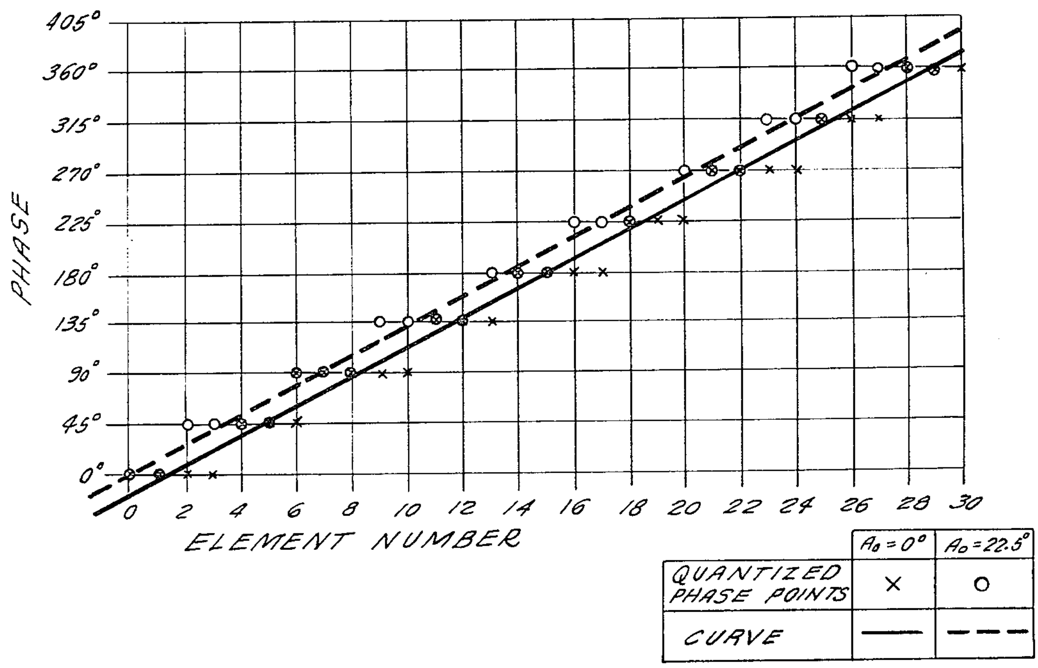


FIG. 4b

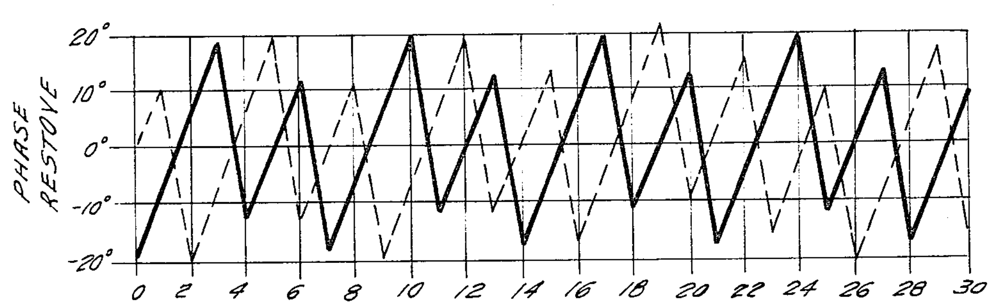
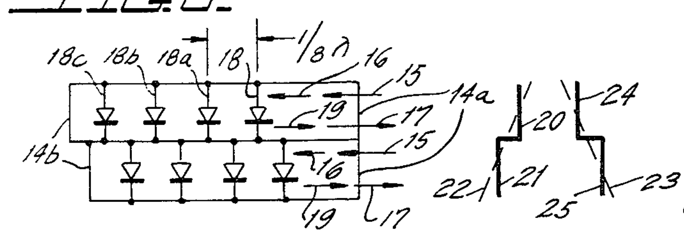


FIG. 3



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ANTENNA ARRAY EMPLOYING AN AUTOMATIC AVERAGING TECHNIQUE FOR INCREASED RESOLUTION

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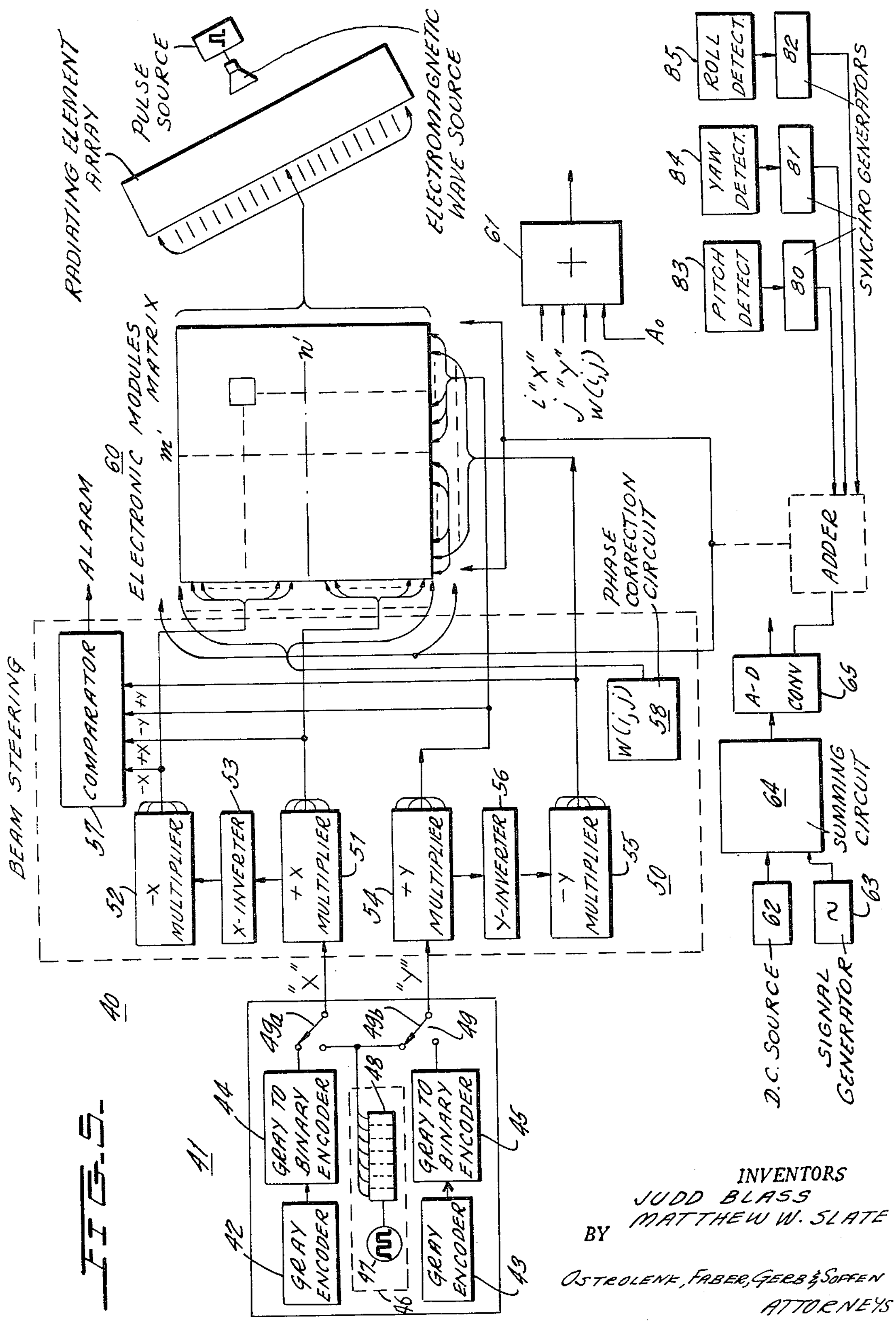

FIG. 5

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ANTENNA ARRAY EMPLOYING AN AUTOMATIC AVERAGING TECHNIQUE FOR INCREASED RESOLUTION

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FIG. 5a.

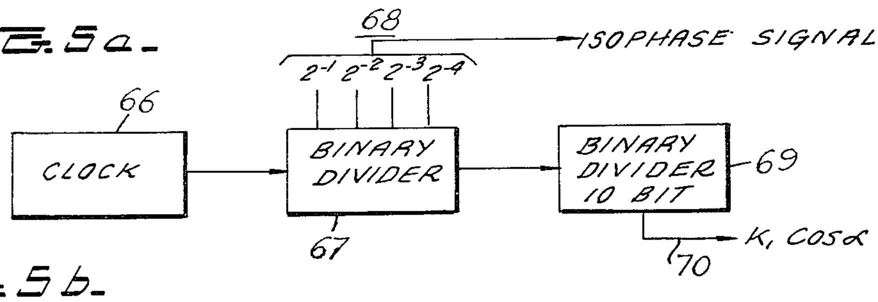


FIG. 5b.

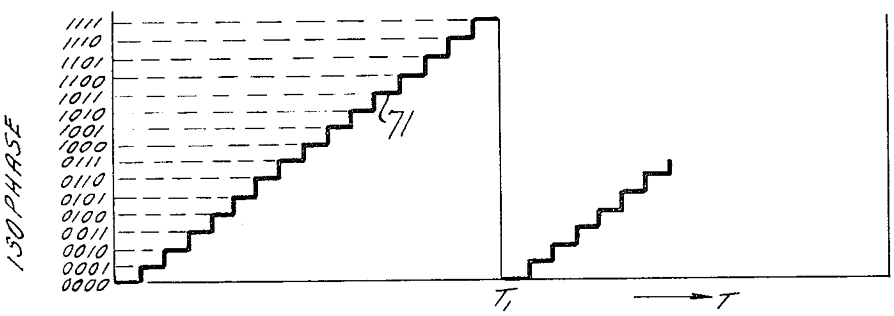


FIG. 5c.

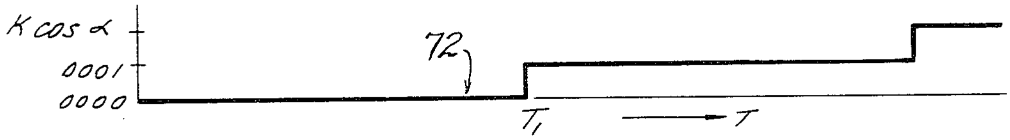
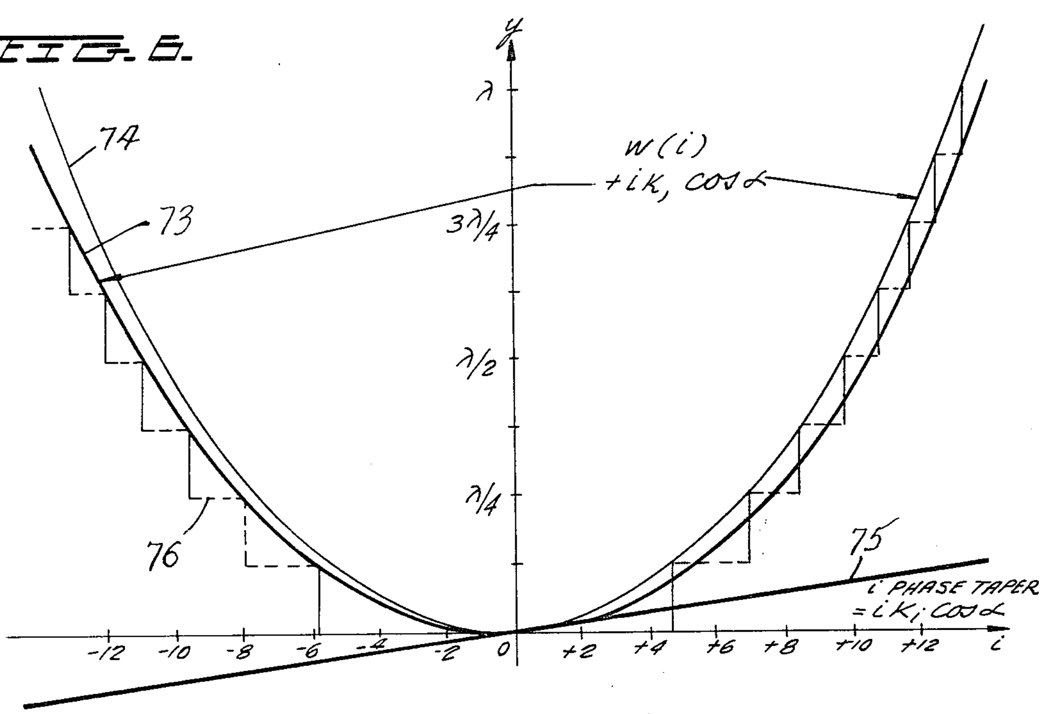


FIG. 6.



United States Patent Office

3,387,301

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3,387,301

ANTENNA ARRAY EMPLOYING AN AUTOMATIC AVERAGING TECHNIQUE FOR INCREASED RESOLUTION

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Filed Mar. 31, 1966, Ser. No. 539,074
13 Claims. (Cl. 343—100)

ABSTRACT OF THE DISCLOSURE

An antenna system comprised of a stationary array of radiating elements and a feed means for directing electromagnetic rays toward the array, which rays are reflected from the array and directed into space. The array is caused to develop a scanning beam by providing control means which selectively controls the phase delay imparted to the electromagnetic waves impinging upon each element of the radiating array thereby developing a scanning beam of relatively narrow beam width. Since the changes in phase delay between adjacent radiating elements is a step-like pattern as opposed to a linear phase taper, the resultant beam pointing error and sidelobe variation is minimized through the application of a signal simultaneously applied to all elements of the array which signal varies in magnitude at a rate at least equal to the repetition rate of electromagnetic wave pulses directed toward the radiating array from the feed means.

The instant invention relates to computational methods and apparatus, and more particularly to novel computational methods and apparatus especially adapted for use in radar systems which act to effectively eliminate beam pointing error and unwanted sidelobes in transmitted radar signals so as to significantly enhance the quality and value of returning radar signals, thereby enhancing overall operation of such radar systems.

Typical radar systems are conventionally comprised of a signal pulse source which is arranged to direct the generated electromagnetic waves to impinge upon a reflecting dish antenna, usually of parabolic surface contour, which reflects the electromagnetic waves, directing them outwardly and away from the parabolic dish, with all of the outgoing waves being substantially parallel to one another. The signal source and parabolic reflector are typically mounted upon a rotatable platform which acts to rotate the antenna assembly at a predetermined number of revolutions per minute. Radar antenna assemblies of this type are usually quite large and require very large spherical shaped enclosures so as to freely permit rotation of the entire antenna assembly. In addition thereto, practical limitations of the assembly structure severely limit the number of sweeps or revolutions per unit time which the assembly may perform. All of these practical limitations have been overcome through use of a novel antenna structure which is completely stationary and has no moving parts.

Antennas of this novel class are described in detail in copending applications Ser. No. 244,089, filed Dec. 12, 1962, now Patent No. 3,274,601, and Ser. No. 409,905, filed Nov. 12, 1964, Judd Blass et al., and which have been assigned to the assignee of the instant invention. One category of such antennas are normally comprised of a plurality of radiating elements arranged in either a linear or a planar array, with each of the individual radiating elements having first open ends and second sealed ends, and a plurality of electronically controlled short-circuiting devices such as, for example, semiconductor diodes mounted inwardly from the open end of each waveguide

section and being spaced from one another by fractions of a wavelength λ where λ is equal to the wavelength of the operating frequency f of the antenna, which operating frequency f may be typically greater than 1 megacycle. Each of the radiating elements are also spaced from one another by some fraction of a wavelength.

In planar arrays, the signal source providing the electromagnetic waves is positioned in front of the planar array, with all of the open ends of the waveguide sections confronting the signal source. The emitted electromagnetic waves move toward the planar array and enter into the open ends of all of the individual waveguide sections. The electromagnetic waves enter into each waveguide section, are reflected at the sealed end thereof, and leave each waveguide section to enter into space and move toward a sector in space.

A phase delay is experienced by each electromagnetic wave, which phase delay is equal to twice the depth in wavelength of each waveguide section, since the electromagnetic wave enters each waveguide section, is reflected at the rear end thereof, and leaves each waveguide section traversing the length of the waveguide section twice. Since the waveguide sections in the planar array are all positioned at differing distances from the energy source, additional phase delay will be introduced to the electromagnetic waves equal to the difference in distances of each of the sections of the array from the energy source. This phase delay may be substantially compensated for by making those waveguide sections which are further removed from the wave generating source shorter in electrical length so that the sum of the phase delay introduced by the waveguide section plus the phase delay introduced by the differing distance from the wave generating source will be substantially equal for all of the waveguide sections over the entire planar array. Thus, the electromagnetic wave source and planar array simulate conventional radar antenna arrays comprised of a wave generating source and a parabolic dish reflector.

In order to simulate the rotational capability of conventional radar antenna assemblies, each of the waveguide sections are provided with a plurality of short-circuiting elements, or semiconductor diodes, as were previously mentioned. It is possible through a central electronic control means to selectively energize one of the group of short-circuiting elements in each of the waveguide sections in order to alter the phase delay for each waveguide section. By appropriate electronic control it therefore becomes possible to collimate the radiation produced by each element so that the antenna radiates predominantly in a particular direction. This control is carried out by "x" and "y" input information signals coupled to the radiating elements.

The "x" input information sets up a cone-shaped radiation pattern having its apex at the intersection between the "x" and "y" axes of the planar array front face and having its longitudinal axis coincident with the "x" axis. The taper of the cone is defined by the angle α.

The "y" input information sets up a second cone-shaped radiation pattern having its apex at the intersection between the "x" and "y" axes of the planar array front face and having its longitudinal axis coincident with the "y" axis. The taper of the second cone is defined by the angle β.

The intersection between the surfaces of the first and second cones determines the direction of radiation (α and β) from the planar array. The half of the cone surface of each of the cones which lies behind the front surface of the planar array may be ignored since radiation occurs in only one direction.

If desired, the interior angle of one cone may be kept constant while the interior angle of the other is varied, or the interior angles of both cones may be changed simultaneously. It should be noted that the interior angles of both cones must be altered when an azimuthal sweep at one elevational angle is desired.

It is thereby possible, through use of the planar array and an electronic control circuit described above, to provide either an independent azimuthal or elevational scan or a combined azimuthal and elevational scan in order to detect fixed or moving objects, and to track aircraft, ships or other moving objects. In the quiescent state, the planar array antenna continually sweeps the horizontal and/or the vertical directions in search of objects of interest. Once the presence of an object of interest is detected by the radar system, it is most important to be able to provide the most accurate data possible to identify location and speed of the singular or plural objects.

Once the azimuthal and elevational position of an object is determined as a result of the sweep operation, it is possible, through the electronic control circuitry, to instantaneously depart from the continuous scanning state and "lock" the antenna in upon the observed flying object. The radiation pattern transmitted into space is comprised of a single or main lobe of relatively small solid angle which is also accompanied by a plurality of side lobes which, though unwanted, do occur as part of the radiation pattern and act to produce spurious reflections from objects illuminated by the side lobes, which may be confused with the signal which returns to the antenna planar array after reflection from the moving object. Such side lobes are present even though antenna optimum design techniques are employed so as to minimize the strength of the side lobes and hence to minimize their harmful effects.

The electronic control of the phase front effectively acts to angularly orient the main lobe so as to point its longitudinal axis directly at the detected object. The angular orientation of the main lobe is controlled by the equation:

$$\psi = i_m K_1 \cos \alpha + j_n K_2 \cos \beta + W\ (i_m, j_n)$$

where α and β represent the angles which the main lobe makes with the horizontal and vertical axes, respectively, and

$$W = \text{spherical correction factor} \quad (1)$$

The planar array which is comprised of a matrix of radiating elements, is preferably arranged in regular matrix fashion having a m columns and n rows, where one row and one column (usually centrally located) may be arbitrarily selected as the references from which the numbers i and j are measured.

The scan angle for the antenna assembly measured from the x and y axes are α and β, respectively. The phase taper (uniform increases in phase from row to row or column to column) of $K_1 \cos \alpha$ or $K_2 \cos \beta$, which are the signals coupled to the individual radiating elements for selectively controlling the activation of the radiating elements' short-circuiting devices, control the scanning of the beam. Absolute phase has no significance and only the phase difference has any effect on the structure. K_1 and K_2 are constants which take into account element spacing and wavelength.

The antenna is electrically collimated to focus radiation at the antenna feed by the "spherical correction function" $W(i,j)$ which provides a phase advance for each element to compensate for the varying distance from the radiating elements to the antenna feed. The spherical correction function is so selected that the phase delay corresponding to the distance from each element to the feed, plus the phase delay minus $W(i,j)$ is a constant.

The three signals required for each radiating element at the ith column and jth row are, therefore, $iK_1 \cos \alpha$, $jK_2 \cos \beta$ and $W(i,j)$. If these three signals are added, the sum $iK_1 \cos \alpha + jK_2 \cos \beta + W(i,j)$ is the precise phase required at the element i, j to point the beam in the desired direction. It should be noted that in all arithmetic operations factors of 2π are dropped. The above terms are generated in binary fashion and, through suitable binary converting means, are interpreted by each radiating element in order to activate the appropriate short-circuiting element in order to selectively "point" the antenna.

As a practical matter, the number of binary bits for which a radiating element digital (i.e., discrete step) phase shifter can be constructed is limited. Therefore, the output signals from the radar assembly electronics, commonly referred to as the beam steering computer, which generates the signals, are truncated (i.e., reduced) to this number. In other words, the function of truncation consists of dropping the least significant binary bit positions which extend beyond the accuracy capabilities of the array. Typical large planar arrays normally employ no more than two or three binary bits. This truncation produces an error distribution over the array. The theoretically continuous or constant variation of phase with displacement in any direction along the array is replaced by a distribution with step variations, which approximate the ideal continuous variation.

The error distribution is not periodic, and, therefore, to a great extent, cancels out. But the error distribution still causes a beam pointing error and side-lobe variation which is a function of nominal beam positions.

In a typical beam steering computer, the multiplied binary scan signals, $iK_1 \cos \alpha$ and $jK_2 \cos \beta$ are truncated before these terms are summed with $W(i,j)$. If the input signals representing beam angle are multiplied by a continuum, the ideal outputs would vary in linear fashion, and the truncated outputs would have distributions with step variations similar to that produced on the antenna aperture by aperture quantization. The fact that the multiplication is by integers only will, for some inputs, obscure this error distribution and for others, a periodic error distribution occurs before summation can result. Therefore, the quantization which takes place before addition must be substantially finer than the aperture quantization for a tolerable degradation of antenna performance.

In order to correct for beam fine pointing variations, a signal A_0 is added to the binary signal for each radiating element. This is defined as Isophase signal because it is constant over the aperture at any time. This signal will have no effect on nominal beam angles α and β because it does not affect the phase tapers. If the signal A_0 is added before final (aperture) quantization (finer than the aperture quantization), variation in this signal will vary the distribution of final quantization errors. While the Isophase signal A_0 will not vary the magnitude of step variations in phase, it will shift the points on the antenna aperture at which these steps occur. If a large number of different Isophase signals are applied (meaning that the Isophase signal is introduced at a point much finer than the aperture quantization), and the resulting radiation patterns are averaged, the beam pointing errors and peak side-lobes will tend to cancel out. The resulting signals are then averaged, whereby the resulting average beam error and side-lobe level will be substantially less than the peak values which occur in the absence of the Isophase signals. The average values may be further improved by increasing the number of wave pulses transmitted to still further smooth out the average errors.

The instant invention is thereby characterized by providing electronic control means for producing the angular orientation terms $K_1 \cos \alpha$ and $K_2 \cos \beta$ in binary form, multiplying those signals of all integers corresponding to the values of i and j for each of the radiation elements of the array contained in the m columns and n rows, where i is the number of a particular column and j is the number of a particular row and where each of these signals are quantized to P bits; generating Isophase signals A_0 in binary form, quantized to q bits, and generating the spherical correction factor $W(i,j)$ in binary form quantized to r bits. The Isophase signals A_0 are added to each of the products $iK_1 \cos \alpha$ and $jK_2 \cos \beta$, where the Isophase signals added to the products $iK_1 \cos \alpha$ are constant for all values of i and may or may not be the same as the Isophase signals added to the products $jK_2 \cos \beta$, which are identical for all values of j. The summations are truncated to r bits, and the three r bit signals corresponding to each element at column i and row j are added, with the sum being quantized to s bits, where s is equal to or less than r.

The quantization of the above terms is performed by any one of a plurality of round-off procedures. For example, let it be assumed that the number 0.56938, which contains five digits, is to be quantized so as to have a length of three digits. One round-off rule which may be applied is if the most significant bit next to the round-off bit is greater than 5, then the round-off bit is increased by 1. Another rule which may be employed is if the most significant bit next to the round-off bit is greater than 4, then 1 is added to the round-off bit. Thus, in the example given using either of these two rules, the quantized result would be 0.569. If the number was to be quantized to 4 bits, the result would be 0.5694. In quantization involving binary numbers, the round-off may be performed by adding 1 to the round-off bit when the most significant binary bit being dropped is in binary 1 and keeping the round-off bit the same when the most significant binary bit being dropped is binary 0. The other rule which may be employed is that of simply making no change whatsoever to the bit being rounded off, regardless of the state of the most significant binary bit being dropped. By alternating between these two possible selections, this will affect the finally quantized signal supplied to each radiating element, thereby altering the points on the antenna aperture at which the phase delay steps will occur. By averaging the returning signals for these two conditions, it is thereby possible to reduce the resulting average beam error and side-lobe level, thereby enhancing the significance of the data returned.

As an alternative embodiment, it should be noted that for any pair of input signals $K_1 \cos \alpha$ and $K_2 \cos \beta$, there will be certain Isophase signals A_0 which will produce minimum error, and that these optimum Isophase signals will vary with variations in $K_1 \cos \alpha$ and $K_2 \cos \beta$. It is possible to compute the relationship between the input signals and the optimum Isophase signals. If this relationship is a simple one, a computational device may be provided to generate and apply the optimum Isophase signals dependent upon the values of the input signals $K_1 \cos \alpha$ and $K_2 \cos \beta$. If the relationship becomes more involved, a pre-computed tabulation, which can be stored in the computer for table look-up procedures may be employed. Thus, as each input signal $K_1 \cos \alpha$ and $K_2 \cos \beta$ is received for providing the antenna beam steering information, this input signal data is then examined and the optimum Isophase signal A_0 is then selected and appropriately summed thereto.

In a preferred embodiment described wherein a plurality of pulses are transmitted and the resulting radiation patterns are averaged, in order to obtain slightly differing beam patterns, all of which have substantially the same phase taper, the Isophase signal A_0 is altered slightly before the generation of each of the pulses thus axially shifting the wave front. For example, the Isophase signal generating means which is either manually or automatically controlled may be a device which generates digital signals in a pre-programmed or random manner, or an analog signal generating means such as a random signal generator means, a sinusoidal signal generator means, or a linear ramp generator means generating a constant changing analog Isophase signal, which is then converted into digital form by a suitable A to D converter means. Since the Isophase signal A_0 varies somewhat for each transmitted pulse, its binary representation will vary, causing the binary information to the radiating elements to be altered slightly for subsequent pulse. However, due to the nature of the Isophase signal that is coupled to every radiating element within the planar array, the phase taper will remain substantially unaltered, but the discrete step variations between adjacent radiating elements, while not varying the magnitude of the step variations, will shift the points on the aperture at which the steps occur. When a number of such pulses are transmitted, each having a slightly differing Isophase signal A_0, are all averaged together, the resulting average beam pointing error and peak side-lobe level will be substantially diminished so as to yield much more accurate data on the flying object being detected.

It is, therefore, one object of the instant invention to provide a novel radar antenna system having circuitry capable of providing tracking data of moving objects which is more accurate than that produced by conventional antenna systems.

Another object of the instant invention is to provide a novel radar antenna system capable of scanning moving or fixed objects without imparting any physical motion to the antenna structure and further employing an Isophase signal for altering the phase front of the antenna to enhance the accuracy of the angle data.

Another object of the instant invention is to provide a novel antenna system for detecting or tracking objects which is comprised of an antenna assembly which experiences no physical movement throughout the operation, and which employs electronic control means coupled with an array of radiating elements and a feed means for simulating the mechanical sweep of conventional antenna systems, and being further comprised of Isophase signal generating means for further enhancing the accuracy of the data developed by the system.

These and other objects of the instant invention will become apparent when reading the accompanying description and drawings in which:

FIGURE 1 is a perspective view showing in simplified block diagram form an antenna system embodying the concepts of the instant invention.

FIGURE 1*a* is a perspective view showing the radiation pattern generated by a planar array under control of "*x*" input signals.

FIGURE 1*b* is a perspective view showing the radiation pattern generated by a planar array under control of "*y*" input signals.

FIGURE 1*c* is a perspective view showing the resulting radiation pattern generated by a planar array under control of both "*x*" and "*y*" input signals.

FIGURE 2 is a front view of the antenna planar array of FIGURE 1.

FIGURE 3 is a schematic diagram showing the internal structure of two of the radiating element sections of the antenna structure of FIGURES 1 and 2.

FIGURE 4*a* is a plot showing the phase changes occurring in an antenna array of linear aligned elements for two different values of Isophase signals.

FIGURE 4*b* is a plot considered in conjunction with FIGURE 4*a* showing the changes in phase residues as a result of two different Isophase signals.

FIGURE 5 is a block diagram showing the electronic control circuitry employed for generating the varying phase fronts to produce beam scanning.

FIGURE 5*a* is a block diagram showing one manner in which the Isophase signal may be generated.

FIGURES 5*b* and 5*c* are waveforms useful in describing the operation of the circuit of FIGURE 5*a*.

FIGURE 6 is a plot showing the phase across an antenna array as a quadratic function of distance from the vertical axis and the phase jumps resulting from an addition of one value of Isophase signal A_0.

Referring now to the drawings, FIGURE 1 shows an antenna system **10** which embodies the principles of the instant invention. The specific antenna array is described in detail in copending U.S. applications Ser. No. 244,089, entitled, Antenna System, filed Dec. 12, 1962 by J. Blass and Ser. No. 409,905, entitled, Antenna System With Increased Bandwidth Capabilities filed Nov. 12, 1964, by J. Blass, both of which applications are assigned to the assignee of the instant invention.

For purposes of understanding the instant invention, it is sufficient to understand that the antenna assembly **10** is comprised of a feed **11** which is designed to direct an electromagnetic wave front **12** toward a planar array **13** comprised of a plurality of individual radiating elements **14** which are preferably arranged in a regular matrix fashion comprised of *m* columns and *n* rows, as shown in FIGURE 2. The front end **14***a* of each radiating element **14** is open, allowing the electromagnetic waves radiated from feed **11** to enter into the open end and to move in the direction shown by arrows **15** and **16**, as can best be seen in FIGURE 3. The rear end **14***b* of each radiating element is sealed with the same conductive material forming the radiating element so as to cause any electromagnetic waves reaching the rear end **14***b* to be reflected so as to move in the reverse direction, as shown by arrow **17** and leave each element. The depth of each radiating element **14** is typically measured in wavelengths λ, or fractions thereof, where λ is the wavelength for the operating frequency *f* of the antenna structure such that *f* is equal to 1/λ. Thus, the electromagnetic wave in entering each radiating element, being reflected at its rearward end 14*b* and leaving the radiating element, undergoes a phase delay which is equal to twice the depth of the radiating element which is measured in wavelengths λ. While the antenna system of FIGURE 1 shows a planar array of radiating elements, it should be understood that a linear array, i.e., a single row of radiating elements, may be employed, if desired, depending only upon the needs of the user. Such linear arrays may preferably receive radiation at one end of the array and may be staggered in the fashion shown in FIGURE 3 so as to correct the phase delay which the signal undergoes in such a linear array, which is set forth in detail in above mentioned application Ser. No. 244,089.

Each radiating element **14** is further comprised of a plurality of short-circuiting elements, conductors **18** through **18***c* which may, for example, be semiconductors, each of which are electrically coupled between the upper and lower surfaces of the radiating element and are positioned predetermined distances apart which are usually of the order of fractions of a wavelength such as, for example, ⅛λ, ¼λ, and so forth. The phase delay which the electromagnetic wave undergoes in entering being reflected and leaving each radiating element may be electronically modified by selectively energizing i.e., short-circuiting one of the short-circuiting elements **18** through **18***c*. For example, let it be considered that the electromagnetic wave moves in the direction shown by arrow **15** to enter the upper radiating element **14**, shown in FIGURE 3. Let it also be assumed that the short-circuiting elements **18** in the upper element is activated. The entering electromagnetic wave will then be confronted with a short-circuited condition at location **18** and will be reflected, as shown by arrow **19**, so as to move out of the radiating element and in the direction shown by arrow **17**. Thus, it can be seen that the phase delay imparted to the electromgagnetic wave entering into the upper radiating element **14** of FIGURE 3 can be substantially reduced by energizing one of the active elements **18** through **18***c*, all of which are located well in front of the rear surface **14***b* of the radiating elements. By energizing the active element **18***a* in the lower radiating element assembly of FIGURE 3, the entering electromagnetic wave moving in the direction of arrows **15** and **16** will be reflected at **18***a* and move in the direction shown by arrows **19** and **17**, respectively, with the active elements **18** and **18***a* being energized in the upper and lower radiating sections **14**, respectively. The points of substantially identical phase will be represented by the phase fronts **20** and **21**, thereby establishing a phase taper substantially as represented by phantom line **22**. It can clearly be seen that the phase fronts change discretely in step-like fashion and not smoothly, as shown by phantom line **22**, but a simulated phase taper will nevertheless be seen to exist if adjacent radiating elements to those shown in FIGURE 3 are controlled in a like manner.

The reverse phase taper, as shown by phantom line **23**, may be produced by selectively activating the active elements **18***a* and **18** in the upper and lower radiating elements, respectively, thus developing the phase fronts **24** and **25**, respectively, substantially resulting in the phase taper **23**.

The antenna feed **11** is supported by any suitable structure (not shown), and receives electromagnetic energy from source **26** which generates electromagnetic waves moving in the direction of the planar array **13**. The planar array **13** of radiating elements **14** are electrically coupled to the output **27***a* of a beam steering computer **27** which is comprised of the electronic control circuitry for selectively activating the active elements (i.e., semiconductors) in each of the radiating elements. By selective operation of the active elements, the beam direction is controlled by planar array **13** in the manner shown in FIGURES 1*a*, 1*b* and 1*c*. For example, considering FIGURE 1*a*, each of the radiating elements are controlled by "*x*" input signals to set up a radiation pattern which is represented by the cone-shaped surface **28** which has its longitudinal axis coincident with the *x* axis of the planar array and which has its apex **28***a* lying at the intersection between the *x* and *y* axes of the planar array. It should be noted that one half of the cone shaped pattern lies behind the front surface of the planar array and therefore has no effect upon the resultant pattern. Control of the radiating elements by the "*x*" inputs determines the taper or angle x_1 of the cone. Control of the "*x*" inputs permits the taper of the cone **28** to be narrowed or widened in accordance with the required beam direction.

FIGURE 1*b* shows the radiation pattern which is obtained by control of the radiating elements through the "*y*" inputs. This radiation pattern is a cone shaped surface **29** having its apex **29***a* at the intersection of the planar array *x* and *y* axes. The longitudinal axis of cone **29** is coincident with the *y* axis. The taper or angle y_1 of cone **29** may be increased or decreased by application of the appropriate *y* input signals to the radiating elements.

FIGURE 1*c* shows the cones **28** and **29** resulting from application of both the *x* and *y* input control. The intersection of the cone surfaces (which is a straight line) represents the direction of the main lobe of the radiation pattern which is transmitted by the antenna.

For example, if the angles *x* and *y* are each 45° then the intersection is a straight line which lies in the surface of the planar array at a 45° angle to the *x* (or *y*) axis. This is represented by vector **30** shown in FIGURE 1.

As the sum of the two angles x_1 and y_1 increases beyond 90° the intersection between the two cones is two straight lines, one directed to the rear and one directed to the front of the planar array. The rearwardly directed vector may be ignored.

Vector **30** represents a forwardly directed intersection for the case where the sum of the angles x_1 and y_1 is greater than 90° (see FIG. 1*b*). The vector **30** may be represented by three component vectors **30***a*, **30***b* and **30***c*. Vector **30***a* is directed along the *y* axis. Vector **30***b* is colinear with the Z axis (which axis is perpendicular to the *x*–*y* plane). Vector **30***c* is colinear with the *x* axis.

The sweep of vector **30** may be controlled in three different ways. The angle x_1 of the cone **28** may be kept constant while the angle y_1 of the cone **29** may be varied; the angle y_1 of the cone **29** may be kept constant while the angle x_1 of cone **28** is varied; or the angles x_1 and y_1 of cones **28** and **29**, respectively, may be simultaneously varied. Any one of the three forms of control may be employed to obtain any desired sweep of the main lobe.

The individual radiating elements are selectively operated to control the activation of one (or more) of their active elements of binary coded information which is impressed upon the electronic control means (not shown) of each of the radiating elements. The manner in which the final binary coded information for each radiating element is formed is in accordance with the phase equation:

$$\psi = iK_1 \cos\alpha + jK_2 \cos\beta + W(i, j) + A_0 \qquad (1)$$

The scan angle from the horizontal and vertical (i.e., x and y axes) are α and β, respectively. A phase taper of $K_1 \cos\alpha$ or $K_2 \cos\beta$ will cause the beam to be scanned at angles α or β, respectively. K_1 and K_2 are constants involving element spacing and wavelength.

FIGURE 5 shows the beam steering electronics. The scan control **41** develops the basic beam steering commands. The horizontal command is a parallel word, typically of eight to ten binary bits. The most significant bit is the coefficient of π in the binary expression of the phase taper required along the horizontal axis. The numerical value of this word is the phase required in terms of the wavelength λ, and is equal to $2a/\lambda \cos X$ (2), where a is the distance between adjacent radiating elements (see FIGURE 2). Similarly, the vertical command is a binary parallel word of approximately equal length. The most significant bit is the coefficient of π in the binary expression of the phase taper required along the vertical axis. The numerical value of this multi-bit word is the phase required in terms of λ and is equal to $2b/\lambda \cos B$ (3) where b is the distance between adjacent radiating elements (see FIGURE 2).

The antenna is electrically collimated to focus radiation at the feed by the "spherical correction function" $W(i, j)$ which is a phase advance for each element to compensate for the varying distance from the radiating elements **14** to the feed **11**. This function is so calculated that the phase delay corresponding to the distance from each element to the feed, plus the phase delay $W(i, j)$ is a constant.

In order to clearly define the signals which each radiating element **14** is to receive, the elements of the planar array (when a planar array is employed) are numbered in accordance with reference axes. One row and one column are arbitrarily chosen as the reference axes from which the numbers i and j are measured, where i and j are integers. For example, considering FIGURE 2, the reference axis may be considered to be the middle column m' and the middle row n'. Values to the right and left of column m' are positive $(+i)$ and negative $(-i)$, respectively, while values above and below row n' are positive $(+j)$ and negative $(-j)$, respectively.

Three signals are required for each element with the radiating element in column i and row j receiving the signals $iK_1 \cos\alpha$, $jK_2 \cos\beta$ and $W(i, j)$. These three signals are added to yield the sum

$$iK_1 \cos\alpha + JK_2 \cos\beta + W(i, j)$$

This sum is the precise phase required in element i,j to point the antenna in the directions α and β. It should be noted that in all arithmetical operations, factors of 2 may be dropped.

In practice, the number of binary bits for which a digital (discrete steps) phase shifter can be built is limited. Therefore, the output signals from the beam steering computer are finally truncated to this limited member of binary bits. Typical large planar arrays use from two to three binary bits, but it should be understood that more or less than this number can be employed. The use of a two to three binary bit output signal produces an error distribution over the planar array. The theoretically continuous variation of phase with displacement in any direction along the array is replaced by a distribution with step variations, which distribution approximates the ideal continuous variation.

The phase of a given element in an optically fed array can be expressed as a function of four variables as given in the following equation:

Phase of element (m, n) =

$$A_0 + \frac{2a}{\lambda} m \cos + \frac{2b}{\lambda} n \cos\beta + W(m, n)$$

$W(m, n)$ is the quadratic phase correction for the finite focal distance. It has been shown by us, that use of coarse phase control e.g. 90 degree phase increments is possible without pattern deterioration because of the quasi-randomizing of the phase residues by the integration of this quadratic phase term into the beam steering computer arithmetic.

The terms in the above equation which contain m and n separately are the phase variables required to steer the beam at the angles corresponding to the direction cosines $\cos\alpha$ and $\cos\beta$. The phase reference at the center of the antenna is A_0; and in the case of analog drive systems has never been considered a variable in the phase control of the antenna. The special purpose beam steering computer performs the arithmetic function of adding these four phase terms, discarding multiples of 2, and rounding off the resultant to the nearest integral multiple of the smallest phase increment. It can be seen that if the quantization is not infinitesimal, i.e. analog, the value of the constant phase term A_0, will affect the "rounding off" resultant.

The results of both a mathematical analysis and an experimental investigation has shown that it is possible to scan the perturbing side lobes due to the phase quantization residues without scanning the main beam itself and thus eliminate the beam pointing errors due to these phase residues. This is accomplished by varying A_0 in steps equal to a fraction of the smallest phase quantization.

For example, the calculated rms beam pointing error of a 25 milliradian beamwidth antenna test was approximately 0.35 milliradians with peak errors as great as 1.2 milliradians. The average error at any beam pointing direction could be reduced to nil by cycling A_0 between zero degrees and 45 degrees in this case by one phase increment. The sidelobes could be varied from −15 db to −24 db even though the theoretical sidelobes in the absence of any phase error was −22 db.

The quantitative explanation for this phenomenon can be sen from the diagram shown in FIG. 4*a*. This shows a graph of the phase distribution across a linear aperture for two values of A_0 and a single scan direction. It is seen that the adjacent phasors will jump to the next phase increment at different points along the array for the cases shown. The phase residues which are the difference between the ideal phase curve and the step phase function is plotted on the base line of this diagram and is designated as FIG. 4*a*. If this phase residue is considered to be a periodic wave, its phase is a function of A_0 which can be made to vary from 0 degrees to 360 degrees by varying A_0 from 0 degrees to 45 degrees. Since the phase of the radiation due to this residue, with respect to the phase of main beam, can be varied, the interference of the phase residue on the beam pointing and on the near sidelobes can also be made to cycle.

For example, if the normal close-in sidelobe of the antenna is −25 db, and the value of a perturbing sidelobe is −31 db, the peak value of the interference between the two sidelobes may go to 21.5 db, but the rms interference would only go to 24 db. In a search mode in which several hits are placed on a target, with Isophase variation between hits, it would be possible to keep the sidelobe level to 24 db for the above example; whereas in the absence of Isophase Control a 21.5 db sidelobe would occur for some angles of scan under the same conditions of interference.

The additions to the beam steering computer equipment which can provide Isophase Control as herein indicated can also be made to vary the cycle phase through

360 degrees. The interference caused by direct reflections from the aperture, direct radiation from the feed, and illumination of the edge of the aperture by leakage currents on the feed, can be made to vary from destructive to constructive so that the rms interference is the resultant. Wherever it is necessary to observe the target, with more than one pulse, the elapsed time may thus be utilized for smoothing the effects of perturbing interference within the antenna system, as well as integrating the receiver noise.

The additional by-product of this Isophase Control is to cycle each phasor even though the main antenna beam is not moving. This equalizes the energy impinging on a phasor in all phase states. Another by-product which may be conjectured at this time is the effect of additional cycling on surface currents which are normally generated in a phased array. The use of an optical source feed and quadratic phase correction eliminates the surface waves that are excited if the phase distribution were completely uniform. The addition of the Isophase Control, however, can also smooth out the residual surface currents which do exist and minimize the normal hot spot derating caused by these currents.

In a typical beam steering computer, the scan signal terms $K_1 \cos \alpha$ and $K_2 \cos \beta$ are multiplied by the appropriate column and row numbers i and j, respectively, and the resulting terms $iK_1 \cos \alpha$ and $jK_2 \cos \beta$ are truncated before being added together. For example, the terms $iK_1 \cos \alpha$ and $jK_2 \cos \beta$ may each be ten binary bits in length. Before the addition step, they are reduced in length to six binary bits, for example. If the input signals $K_1 \cos \alpha$ and $K_2 \cos \beta$ were multiplied by a continuum, the ideal outputs would vary in linear fashion and the truncated outputs would have a distribution with step variations similar to that produced on the aperture by aperture quantization. The fact is that the multiplication by integers (i and j) only will, for some outputs, obscure this error distribution, but for others a periodic error distribution can result. Therefore, the quantization before addition must be substantially finer than the aperture quantization for a tolerable degradation of the performance.

FIGURE 5 is a schematic diagram showing the electronics employed for controlling beam position. The circuitry **40** is comprised of a scan control **41** which develops the basic beam steering commands which are the terms $2a/\lambda \cos \alpha$ and $2b/\lambda \cos \beta$, which have been previously described. The scan control circuit **41** is comprised of two 8-bit shaft encoders **42** and **43** generating a gray code output. The outputs of these shaft encoders are coupled to gray-to-binary decoders **44** and **45**, respectively, to deliver two independent scan signals at the operator's control. The beam can be manually slewed in one or both coordinates by this means. The scan generator **46** is comprised of a clock-pulse generator **47** which triggers an 8-bit binary divider **48** which, in turn, develops an 8-bit binary word at its output terminals to provide a digital bit-by-bit scan of the entire 140° sector covered by the antenna along either principal axis. Switch means (not shown) electrically connected to the divider circuit **48** may be provided for the purpose of permitting coarse scan steps with as many as desired of the 8 bits being fixed. If it is desired to scan one output and slew the other output, the switch means **49** may be employed so as to couple the X scan control output to the gray-to-binary encoder **44** and the Y scan output to the binary divider circuit **48**. By operating switch means **49** in the reverse direction from that shown, the X output is coupled to the binary divider **48** and the Y output is coupled to the gray-to-binary encoder **45**. This arrangement thereby permits a scan along one principal axis with the position along the other being set. If desired, both outputs X and Y may be taken in parallel from the binary divider. This could be done simply by maintaining lower switch arm **49**b in the position shown in FIGURE 5 and coupling upper switch arm **49**a to the output of divider **48** and decoupling it from the output of gray-to-binary encoder **44**.

The sweep may be maintained indefinitely with the binary divider circuit automatically resetting itself after reaching its maximum capacity. The shaft encoders **42** and **43** may be set either manually or automatically. In order to provide the capability of instantaneously terminating continuous sweeping for the purpose of obtaining a "fix" on a particular object which has been detected, the binary state of divider circuit **48** is ascertained, and the shaft angle encoders **42** and **43** are automatically set to provide the proper X and Y output signals to as to fix the antenna system to point toward the desired sector in space. This circuitry has not been described in detail herein, as the capability afforded by such circuitry lends no novelty to the device of the instant invention. For a description of this circuit, see application Ser. No. 230,358, filed Oct. 15, 1962.

The output signals representative of the cosine information are passed to the beam steering circuit **50** which forms the required phase tapers by generating for each row and column the phase difference from the zero or reference row and column m' and n', respectively, referred to previously. The beam steering circuitry is comprised of positive and negative X multiplier circuits **51** and **52**, respectively, and an X inverter **53** to generate all the X signals by multiplying the X command by all integers from $-n$ to $+n$ for the total number of columns in the planar array. Likewise, the beam steering circuit **50** is comprised of a positive and negative Y multiplier circuit **54** and **55**, respectively, and a Y inverter circuit **56** to multiply the Y command signals by all integers from $-n$ to $+n$ to provide a signal for each row of the planar array. The X and Y multiplier circuits are preferably D.C. coupled logic circuits which function as adders to form the appropriate output signals. In order to form any even numbered output (i.e., 2X, 4X, et cetera), this may be achieved simply by shifting the bniary word 1-bit position toward the left for multiplication by two, 2-bit position toward the left for multiplication by four, 3-bit positions to the left for multiplication by eight, and so forth. This −X multiplier circuit **52** operates substantially in the same manner. In order to insure that the multiplication operations have been carried out correctly, a comparator circuit **57** is provided for comparing +X and −X outputs, −2X and +2X outputs, −3X and +3X outputs, et cetera. If the resultant sum of these comparisons is zero, operation continues in normal fashion. If the comparison operation detects a difference signal, alarm indication is provided at its output, which alarm indication may be employed for the purpose of terminating operation, providing an audio-visual alarm signal, and so forth. The +Y and −Y multiplier circuits **54** and **55**, respectively, also operate in a similar manner, and associated positive and negative generated signals are likewise compared in comparator circuit **57** to assure generation of accurate signals.

The beam steering circuit **50** is further comprised of a spherical phase correction circuit **58** which is an electronic circuit for providing the necessary phase correction for phase delays introduced due to the differences in distance from the antenna feed. For example, it is very clear that electromagnetic waves will arrive at the radiating elements at the extreme left and right-hand ends of the planar array **13**, later than such electromagnetic waves will arrive at the radiating elements which like in the immediate region of the feed longitudinal axis **11'**. Output signals are thereby developed by circuit **58** for each of the radiating elements in the planar array, such that this signal, when added to the phase delay corresponding to the distance of the element to the feed, is a constant. Since these corrections are substantially constant for any given antenna array the spherical correction factor for each radiating element may be pre-wired into its associated adder.

The outputs of the multiplier circuits **51, 52, 54** and **55** and the spherical phase correction circuit **58** are impressed upon the electronic module matrix **60** which is a regular matrix of adder circuits such as, for example, the adder circuit **61**, arranged in *m* columns and *n* rows, with each of these adder circuits being designed to accept the associated X and Y input, together with the spherical phase correction input, to form the sum

$$i_1j_1 \cos \alpha + j_1K_2 \cos \beta + W(i_1j_1)$$

which signal is the precise phase condition required by element i_1j_1 in order to point the antenna in the directions α and β. The adder circuits such as, for example, the adder circuit **61**, may, for example, be comprised of a parallel three-binary bits output which is suitably amplified and impressed upon the short-circuiting elements of the associated radiating elements to obtain the desired phase taper.

The binary output of the scan control circuit is delivered to *p* bits when impressed upon the inputs of the X and Y multiplier circuits. After multiplication of inputs by all integers corresponding to the values of *i* and *j*, the outputs of the multiplier circuits are then quantized to *r* bits, where *r* is equal to or less than *p*. The outputs of the spherical correction factor circuit **58** are also quantized *r* bits. The adder circuits such as, for example, the adder circuit **61**, receives the information quantized to *r* bits and delivers the sum quantized to S bits where S is equal to or less than *r*.

Once an object has been detected during quiescent operation and it is then desired to obtain a "fix" on such an object, the electronics locks in on the desired sector. The Isophase signal is then employed at this time to obtain very accurate data on object location.

In radar tracking operations, when more than a single pulse is returned by a target, the several pulses are Isophase corrected during the period of a single "fix" in a manner to be more fully described. Since radar targets are typically slow moving in relation to the speed of electromagnetic propagation and the radar pulse repetition rates being in the order of hundreds or thousandths of pulses per second, it may be considered that several pulse returns from the target are being returned from effectively the same fixed position in space.

Isophase operation is obtained by employing the electronic control circuitry **40** in a manner such as to feed angular information repersenting α and β into the circuit **50** for a specific beam orientation, and Isophase signal A_0 is then added to the terms

$$iK_1 \cos \alpha + jK_2 \cos \beta + W(i, j)$$

The magnitude of the signal A_0 is altered prior to the generation of each pulse to be transmitted from the antenna feed **11** so that the resulting sum

$$iK_1 \cos \alpha + jK_2 \cos \beta + W(i, j) + A_0$$

is a slightly different number for each transmitted pulse. In the circuitry of FIGURE 5 this is obtained by providing a constant A_0 generating circuit **62** which is capable of either being manually or automatically controlled to develop a constant binary output level. This constant binary output is fed into a summing circuit **64** together with the output of a signal generator **63** so that the resulting output of summing circuit **64** is constantly changing at a rate determined by the signal repetition rate of the signal generator **63**. Signal generator **63** may be a random signal generator, a sinusoidal signal generator, a staircase wave signal generator, a sawtooth wave signal generator, or any other suitable signal generating means which provides a constantly changing output level with either a regular or random repetition rate. If desired, the constant output means **62** and sum circuit **64** may be omitted, and the signal generator means **63** alone may be used to apply the Isophase signal A_0 to each of the adder circuits in electronic matrix **60**. The output of adder circuit **64** may be converted to binary form in any suitable manner, such as A-to-D converter **65**. If desired, any suitable binary output device may be employed in lieu of the Isophase generating circuit of FIGURE 5.

Another manner of developing the Isophase signal A_0 is shown in FIGURES 5*a* through 5*c*. In the arrangement of FIGURE 5*a*, a clock-pulse source **66** is provided for generating output pulses at a constant repetition rate. These output pulses are impressed upon the input of a first stage of a multistage binary divider or binary counter circuit **67** where the outputs of each of its multiple stages are available at **68** for developing the Isophase signal. The output of the last stage of binary divider circuit **67** is impressed upon the first stage of a second multistage binary divider circuit **69** with the output of each of its multistages being available at **70** to develop the signal $K_1 \cos \alpha$. The binary divider, or counter circuit **66**, develops an output represented by waveform **71**, shown in FIGURE 5*b*. For example, considering the binary divider circuit **67** as being comprised of four stages, the state of the output circuit for increasing time is represented by each discrete step of the staircase waveform **71**. As soon as the final step (i.e., the binary state 1111) is achieved, the binary divider circuit **67** automatically resets itself to begin stepping through another complete cycle beginning at time T_1, for example. As soon as the binary divider circuit **67** resets itself, a pulse is provided to the input of binary divider circuit **69** at time T_1, causing the output to increase its count by one binary bit as represented by the step waveform **72**, shown in FIGURE 5*c*.

The signal A_0 is defined as the Isophase signal because it is constant in value over the aperture of the planar array at any instant of time. The signal A_0 has no effect on nominal beam angles α and β since it does not affect the phase taper. If the signal A_0 is added before final quantization, which takes place at the aperture of the antenna and is finer than the aperture quantization, variation in the signal in the manner taught by the circuitry of FIGURE 5*a* or the circuitry **62** through **65** of FIGURE 5, the variation or change in the signal A_0 varies the distribution of the final quantization errors.

Considering FIGURE 6 curve **73** shows the phase of the radiating elements as a quadratic function of the radiating elements in the "*x*" direction. The curve **70** is the corrected curve which results when the spherical correction factor **71** is added to the terms $iK_1 \cos \alpha$. The resulting linear phase taper is shown by (straight line) curve **75**. The phase shift which results from an addition of the Isophase signal A_0 which is equal to 22.5° phase increase. The phase jumps shown by step-like curve **76** occur each time a 45° phase increase occurs. For example, the fifth radiating element to the right of the *y* axis is the first element to change its phase front upon application of the Isophase signal A_0. By adding a constant signal A_0 to each of the radiating elements, which constant signal has a value smaller than the phase differences between adjacent phase fronts, then there will be an insufficient amount added to the total phase signal ϕ [see Equation (1)] to cause an incremental change in phase between each and every adjacent radiating element.

In a system which uses Isophase to integrate out aperture quantization error, the beam steering computer will also accept A_0 quantized to *r* bits, and deliver, quantized to *s* bits the sum of

$$\underbrace{\underbrace{iK_1 \cos \alpha}_{r \text{ bits}} + \underbrace{jK_2 \cos \beta}_{r \text{ bits}} + \underbrace{W(i, j)}_{r \text{ bits}} + \underbrace{A_0}_{r \text{ bits}}}_{\text{sum quantized to } s \text{ bits}}$$

It should be noted that only certain bits in A_0 are logically significant. More significant bits may be included for other purposes such as error checking, and equalization of power dissipation by switching between states which are logically identical in terms of beam steering, but physically different. In the above case those bits in A_0 less significant than s are logically significant.

In a system which uses Isophase to integrate out multiplier quantization errors the beam steering computer will also accept A_0 quantized to more than r bits and add it before the multiplier quantization.

$$\underbrace{\underbrace{\underbrace{iK_1 \cos\alpha}_{p \text{ bits}} + \underbrace{A_0^{I}}_{q \text{ bits}}}_{r \text{ bits}} + \underbrace{\underbrace{jK_2 \cos\beta}_{p \text{ bits}} + \underbrace{A_0^{II}}_{q \text{ bits}}}_{r \text{ bits}} + \underbrace{W(i, j)}_{r \text{ bits}}}_{\text{sum quantized to } s \text{ bits}}$$

The two Isophase signals A_0^{I} and A_0^{II} need not be identical. In each, bits less significant than p contribute to integration of multiplier output (adder input) quantization, and, therefore, should be present in both A_0^{I} and A_0^{II}. In each, bits equal to or greater than r in significance and less than s will be transmitted directly to the final addition where they will integrate out aperture quantization errors. These last bits need be present in only one of the two Isophase signals. Those bits present in both Isophase signals need not vary synchronously; best integration requires them to be independent.

In practice, the number of Isophase bits to be used will be a compromise among factors such as increasing cost of hardware and increased integration time, and asymptomatic improvements as the number of bits used is increased. For integration of either aperture or adder quantization errors, the most significant bit of those logically significant will have the greatest smoothing effect, and this smoothing effect will decrease with decreasing significance.

Isophase conceivably can be used in another manner. It is evident that for any pair of input signals $K_1 \cos \alpha$ and $K_2 \cos \beta$ there will be certain Isophase signals which will produce minimum error, and that these optimum Isophase signals will vary with $K_1 \cos \alpha$ and $K_2 \cos \beta$. It may be possible by the use of a computer to determine a relationship between the input signals and the optimum Isophase signals. If the relationship is simple, a simple computational device will be able to generate and apply the optimum Isophase signals from the input signals. If the relationship is more involved, a precomputed tabulation with look-up may be practical.

The Isophase signal may be employed in substantially the same manner as has been described above to provide other novel functions. For example, in the case of antenna systems installed in moving objects such as, for example, marine craft, the pitch, yaw, and roll of the ship contribute to unwanted movement of the antenna array. The Isophase output of FIGURE 5 may then be combined with or substituted by the outputs of suitable attitude control synchro generators **80**, **81**, **82** for generating signals representative of instantaneous changes in pitch, yaw and roll detected by circuits **83–85**, respectively, generating signals of equal magnitude and opposite polarity to compensate for changes in pitch, yaw and roll so as to develop a resulting signal to effectively electronically operate the antenna array to simulate a stationary mounted antenna system. Any other changes in attitude of other craft such as aircrafts may also be employed for the correction of change in attitude of the antenna assembly so that its operation simulates a stationary mounted system.

It can be seen from the foregoing that the instant invention provides a novel electronic control means which employs a time-changing Isophase signal which is constant over the antenna array at any given instant so as not to substantially alter the phase taper of the electromagnetic wave front, but which shifts the location of changes in phase along the aperture and which averages a plurality of returning pulses to thereby produce a resultant averaged signal which greatly diminishes beam pointing error and unwanted sidelobe effects.

The addition of several Isophase signals to the α and β data and the spherical correction factor data at one beam pointing position causes the beam to deviate slightly about a nominal beam pointing position. The returning signals from the target are then integrated by use of a plan-position indicator scope having long persistent characteristics and together with the observer's eye provides the desired integration of the slight variation in returning signals. A variety of Isophase values provided both positive and negative movement about the nominal beam direction causing smoothing of unwanted sidelobes and improvement in beam pointing.

The Isophase signals also have the advantageous side effects of equalizing power dissipation over the antenna aperture and averaging out the effects of mutual coupling between the radiating elements surface reflections and element random phase errors.

Whereas the description given herein relates to an active antenna system which transmits electromagnetic radiation for tracking objects, it should be understood that the antenna array may be operated in a passive manner by controlling the phase of the radiating elements to precisely track objects such as active satellites which transmit their own signals.

Although this invention has been described with respect to its preferred embodiments, it should be understood that many variations and modifications will now be obvious to those skilled in the art, and it is preferred, therefore, that the scope of the invention be limited not by the specific disclosure herein, but only by the appended claims.

What is claimed is:

1. In an antenna system comprising a stationary array of radiating elements, a feed means for directing electromagnetic waves generated at a predetermined repetition rate toward said array to produce a beam; phase control means selectively coupled to said radiating elements for controlling the phase delay of the radiating elements in the array to cause the beam to scan a region in space, the improvement comprising first means for producing a signal which is simultaneously coupled to all of said radiating elements for altering the phase delay imposed upon the electromagnetic waves by said phase control means; said first means including second means for altering the magnitude of said signal at a rate at least as rapid as the repetition rate of said feed means.

2. The system of claim **1** wherein said first means includes means for generating at least two successive signals of differing magnitude.

3. The system of claim **1** wherein said output of said first means is in parallel binary bit form comprised of at least two binary bits.

4. The system of claim **3** wherein said first means is comprised of a high frequency oscillator means; said second means being comprised of a multistage binary divider for generating a parallel a bit output where a equals the number of stages of said binary divider.

5. The system of claim **1** wherein said radiating elements are comprised of third means for reflecting said electromagnetic waves after a first predetermined phase delay; and fourth means under control of said first means for selectively altering the first phase delay.

6. The system of claim **5** wherein said first means is comprised of fifth means for generating binary signal groups for each of said radiating elements to control the pointing of said beams through alteration of the phase delay by each of said radiating elements.

7. The system of claim **1** further comprising means coupled to each of said radiating elements for generating spherical correction factor signals to correct for differing phase delays introduced by said radiating elements due to their differing distances from the feed means.

8. The system of claim **6** further comprising sixth means coupled to each of said radiating elements for generating spherical correction factor signals to correct for differing phase delays introduced by said radiating elements due to their differing distances from the feed means.

9. The system of claim 6 wherein said fourth means is comprised of means for summing the outputs of said phase control means and said first means to generate an output signal; said fourth means including a plurality of short-circuiting means selectively controlled by said output signal to alter said first phase delay.

10. The system of claim 8 wherein said fourth means is comprised of means for summing the outputs of said phase control means, said sixth means and said first means to generate an output signal; said fourth means including a plurality of short-circuiting means selectively controlled by said output signal to alter said first phase delay.

11. The system of claim 1 wherein said first means is further comprised of sensing means for sensing the attitude of said system when mounted upon a movable surface; means coupled between said attitude sensing means and said radiating elements for generating compensating output signals when a change in attitude is detected, controlling said radiating elements to cause said planar array to operate as though no change in attitude has occurred.

12. An antenna system comprising a stationary array of receiving elements;

feed means for receiving electromagnetic waves reflected from said array toward said feed means to provide a receiver beam;

means for controlling the phase delay of the elements to cause the beam to scan a region in space, each of the elements having input means for receiving the signals controlling the scan in space;

the improvement comprising first means to simultaneously deliver the same signal to the input means of each element to alter the phase delay imparted to the electromagnetic waves by said phase delay control means and second means to cause said signal delivered to the input means to vary in either a controlled or random manner.

13. An antenna system comprising a stationary array of radiating elements;

feed means for directing electromagnetic waves toward said array to produce a transmitted beam, means for selectively controlling the phase delay of the radiating elements to cause the beam to scan a region in space;

each of the elements having input means for receiving the signals controlling the scan in space from said scan controlling means;

the improvement comprising first means for simultaneously delivering the same signal to the input means of each element to alter the phase delay imparted to the electromagnetic waves by said phase delay control means and second means to cause the signal delivered to the input means to vary in either a controlled or random manner.

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