1 228 867

PATENT SPECIFICATION (11) 1 228 867

DRAWINGS ATTACHED

(21) Application No. 26827/68 (22) Filed 5 June 1968
(31) Convention Application No. 649 915 (32) Filed 29 June 1967 in
(33) United States of America (US)
(45) Complete Specification published 21 April 1971
(51) International Classification G 01 s 9/22 1/44
(52) Index at acceptance
H4D 376 398 406 411 416 430 511 512 53X 630 632 636 652 653 659
H3R 9M5
H4A 4A2X 4P2 4V2R 4V3 4V4C 6D 6G
(72) Inventor RUSSELL HOOD LOGAN

(54) IMPROVEMENTS RELATING TO RADAR

(71) We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organised according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a radar employing beam scanning.

A tracking radar system measures the coordinates of a target and provides data which may be used to determine the target path and to predict its future position. Tracking radar sytems may be roughly classified as sequential lobing or simultaneous lobing. The information available from a tracking radar system is usually presented on a cathode-ray-tube display for observation by an operator, and may also be supplied to a system which indicates the target path, speed, and its probable future position.

Sequential lobing radar systems, which include conical scanning radar systems, direct a pulsed antenna beam about a target in a sequential pulse pattern. Each pulse returning from the target yields range data. However, at least three pulses are required to obtain the angular position in a two-dimensional system.

An extension of the sequential lobing radar systems is the conical scan radar system which continuously rotates an offset antenna beam. This is in contrast with discontinuously stepping a radar beam betwen three or four discrete positions as in the sequential lobing radar. In a conical scan radar system, the echo signal is employed to generate an error signal for a servo control system which causes the beam to rotate and continually position the antenna on the target.

Simultaneous lobing radar systems use monopulse techniques to process several beam lobes simultaneously to yield both range and angle data from each echo pulse. More than one antenna beam is used simultaneously in these systems, in contrast to the conical scan or sequential lobing system where one antenna beam is employed on a time-shared basis. In both the sequential lobing and conical scan tracking systems, the measurement of angular error in two orthogonal coordinates requires transmission and reception of several pulses. In the time interval during which a measurement is made with either of the latter systems, angular accuracy is degraded if the series of echo pulses contain amplitude-modulation components other than the modulation produced by scanning. If the echo pulse train contains additional modulation components caused, for example, by a fluctuating target cross section, tracking accuracy may suffer, especially if the frequency components of the fluctuations are near or at the conical-scan frequency or the sequential lobing rate. Errors thus arise in control of servos in antenna-pointing control loops.

Simultaneous lobing monopulse radar systems avoid the errors from the relatively low-frequency target amplitude fluctuations because the angular information from each pulse is determined by means of a phase and/or amplitude comparison of the several lobes. Pulse-to-pulse amplitude fluctuations of the echo signal have no effect on tracking accuracy if the angular determination is made on the basis of one pulse from two or more beams rather than many pulses from one beam. Although simultaneous lobing mono-pulse systems offer greater accuracy, they require a multiple receiver channel for echo lobe processing.

According to the present invention, a

radar system having a multi-element antenna includes first beam steering control means for individually establishing the phase of the signals transmitted from each element of said antenna to steer the antenna beam, a second control means for modifying the phase of the signals established by said first control means to steer the antenna beam within the time duration of each transmit pulse completely over a predetermined scan trajectory relative to a scan axis for production of return signals from targets which, when displaced from the scan axis, are amplitude modulated, and receiver means connected to the said second control means and to said elements to utilize the return signal to produce a signal dependent upon said amplitude modulation which is representative of the relation between the scan axis and the target direction. Preferably the second control means is operable to modify the phase established by the beam steering control means and transmitted by said elements so that the antenna beam traverses a plurality of scan trajectories during the period of each transmit pulse. In a system according to the invention, the reliability and flexibility inherent in a radar system having beam steering capability can be retained while obtaining the benefits derived from the sequential lobing and simultaneous lobing systems referred to above.

More particularly, in one embodiment of the invention, conical scan techniques are used in conjunction with monopulse techniques associated with simultaneous lobing systems to provide a novel or improved radar system in which, during each transmit period, at least one complete conical scan of the beam in time and space is accomplished. Such a system is hereinafter referred to as a "conopulse" radar system and the term "conopulse" also is used herein descriptively in conjunction with components and functions directly utilized in providing this result. The amplitude and phase of the signal transmitted from each antenna element are controlled individually in order to obtain a desired beam pattern and angle. Where the antenna is an extensive array of radiators, in addition to controlling the elements on an individual basis, they are also controlled in sections by varying the phase of the transmit oscillator signal so that the beam is caused to follow the desired conical trajectory. The return pulse is then employed to extract range and angle of the target.

A more complete understanding of the invention and its advantages will be apparent from the following description of the accompanying drawings illustrative of the invention.

FIGURE 1 is a simplified block diagram of a beam shaping circuit;

FIGURE 2 is a block diagram of a control system for one radiating element;

FIGURE 3 is a schematic of three radiating elements;

FIGURE 4 is a schematic of a phase controlling circuit;

FIGURE 5 illustrates combining altering modulation signals;

FIGURE 6 illustrates received signals for a target on the scan axis of the beam;

FIGURE 7 illustrates received signals, with a target displaced from the scan axis of the beam; and

FIGURE 8 illustrates operation upon the return signal of FIGURE 7.

The invention will first be described in terms of a land based or airborne tracking and navigation radar employing as a radiator hundreds of elements in a complex phased array and excited to produce one or more conical scans of the beam within the period of each transmit pulse. It will then be shown that the invention may be employed with less complex radiators, so long as they have beam pointing capability, for operation in line or rotational scanning modes.

Referring to FIGURE 1, there is shown an antenna 11 consisting of a planar array of radiating elements. Such an array, generally well known, may be comprised of hundreds of individual radiation elements or antennae to form the single array. As disclosed in U.S. Patent No. 3,238,528, the elements of antenna 11 are controlled individually to shape and direct the beam 11a. In the embodiment of this invention now to be described, the array is also controlled by quadrants A, B, C, and D, one set of arbitrary quadrant boundaries being shown in FIGURE 1. In this system a beam is produced which, during the period of each transmit pulse (e.g. 10 microsec.), follows a patern 11*b* which is conical in time and space. More particularly, a lower side band modulator 12 is connected to quadrant A (Q_A) to generate a phase-modulated radio frequency signal. One input of modulator 12 is connected to the output of a transmit reference oscillator 17. The other input is connected to a sin ω_{ct} or in-phase output of a conopulse oscillator 18. Similarly, a lower side band modulator 13 applies a phase modulation of the radio frequency signal to the elements located in quadrant C(Q_C) of the antenna 11. An uper side band mondulator 14 is connected to quadrant B (Q_B). An upper side band modulator 16 is connected to quadrant D (Q_D). The phase modulated RF signals are to be applied to the elements of array 11 in the respective quadrants. The transmit reference oscillator 17 is connected to one input of each of the modulators 12, 13, 14 and 16. Oscillator 17 provides the high frequency output (ω_o) signal that is to be phase modulated by modulators 12, 13, 14 and 16. The cono-

pulse oscillator 18, (frequency $\omega_o < \omega_o$) is connected to the modulators 12, 13, 14 and 16. It supplies a sin ω_{ot} or in-phase output to modulators 12 and 14 and a cos ω_{ot} or quadrature-phase output to modulators 13 and 16.

FIGURE 2 illustrates a modulator circuit 12 which utilizes a hybrid junction such as a magic T or its equivalent. Modulators 13, 14 and 16 may be of the same construction. Modulator 12 may consists of four arms 19, 21, 22 and 23 having a junction point 24. The oscillator 18 is connected to the arm 21. The signal from oscillator 18 is divided equally between the arms 19 and 22. The reference oscillator 17 is connected to the arm 23. Its signal also is divided equally between the arms 19 and 22. In modulator 12 none of the energy from the pulse oscillator 18 enters the arm 23 and none of the energy from the reference oscillator 17 enters the arm 21. A Schottky barrier mixer diode 26 or equivalent functional non-linear device is connected in the arm 22 and a similar diode 27 is connected in the arm 19. Diodes 26 and 27 are positioned at equal distances from the junction point 24. An open-ended quarter wavelength stub 28 connects to diodes 26 and 27 and to the output line 29.

In operation, the oscillator 18 signal is divided equally between lines 19 and 22. The signal in one arm 19 is 180° out of phase with the signal in the arm 22. The signal from the reference oscillator 17 is also divided equally betwen lines 19 and 22 but both these signals are in phase. The result is that at one of the modulator diodes the two signals are in phase and in the other they are 180° out of phase. The open-ended quarter wavelength stub 28 serves to limit the output frequency of the modulator to the difference between the frequencies of the pulse oscillator, 18, and the reference oscillator, 17.

In FIGURE 1 the output of the conopulse oscillator 18, as applied to the modulators 12 and 14, is 90° out of phase with the output connected to the modulators 13 and 16. The output of the modulators 12 and 14 is shown vectorially in FIGURE 1 by plots 12a and 14a. Vector 14b represents the output of oscillator 17 rotating in the direction of arrow 14c. The signal from conopulse oscillator 18 is represented by vector 14d rotating in the direction of arrow 14e. The same phase relations exist in plot 12a except that conopulse vector 12d rotates in the opposite direction as indicated by arrow 12e.

FIGURE 5 illustrates vector representations of the output signal from all of the four modulators 12, 13, 14 and 16. In each of the four plots the vector OZ represents the output of the transmit oscillator 17 at a given instant of time. The output of each modulator will be dependent upon OZ and the position of the vector representing the output from the conopulse oscillator 18. For the modulator 12 the vector ZA (OZ>ZA) rotating in the direction of arrow 12e represents the output of the conopulse oscillator 18 connected to the modulator 12. The resultant vector OA represents the signal connected to quadrant A of the array antenna 11. The phase of the signal connected to all the radiating elements in quadrant A is the angle ØA between the vector OA and the reference axis *x*. For modulator 13, the vector ZC (OZ>ZC) rotating in the direction of the arrow 13e represents the output of the conopulse oscillator 18 connected to the modulator 13. The resultant vector OC represents the signal connected to quadrant C of the array antenna 11. The phase of the signal connected to quadrant C is the angle ØC between the vector OC and the reference axis *x*. Similarly, the signal connected to quadrant B of the array antenna 11 is represented by the vector OB and the phase of this signal is the angle ØB between vector OB and the reference axis *x*. The signal connected to quadrant D of the array antenna 11 is represented by the vector OD and the phase of this signal is the angle between the vector OD and the reference axis *x*. Note, that the vector ZC is 90° out of phase with the vector ZA, the vector ZB (OZ>ZB) is 180° out of phase with the vector ZA, and that the vector ZD (OZ>ZD) is 180° out of phase with the vector ZC. Thus, as a result of mixing the reference oscillator signal with the conopulse oscillator signal, the phase of the signal connected to the radiating elements in each quadrant of the array antenna 11 is different from the phase of any other quadrant. As a result, the beam traverses a conical trajectory within each transmit pulse period of the radar.

As shown in FIGURE 4, the signals from the transmit oscillator 17 and the conopulse oscillator 18 are combined in the modulator 12. Connections to the modulator for quadrants B, C and D are indicated by Q_B, Q_C and Q_D respectively. The output of the modulator 12 is connected to a phase control circuit 31 in a control module 32 which module controls radiating element 33. Leads to other control modules from the modulator 12 are also shown in FIGURE 4. When the radiating element 33 is in the transit mode, the signal from the phase controller 31 is amplified in the transmitter amplifier 34 and applied to the radiating element 33 by means of a TR switch 36. In the receiving mode, the radiating element 33 senses the signal which is transmitted to a receiver amplifier 37 through the TR

switch 36. The return signal then passes through the phase control circuit 31 to a receiver 39. The receiver 39 compares the phase of the return signal with the phase of the signal generated by the conopulse oscillator 18. From this operation three signals are generated and applied to a steering unit 41 for controlling the phases of the signal transmitted from the individual elements in the array including radiating element 33. The operation of the receiver 39 in conjunction with the steering unit 41 to control the phase of the individual radiating elements is described in U.S. Patent No. 3,238,528. A preferred system is disclosed in U.S. Patent No. 3,417,393.

In FIGURE 3, the module 32 connects the radiating element 33 in the modulator 12. Also connected to the modulator 12 is a control module 43 for a second radiating element 44 and a control module 46 for a third radiating element 47. The control modules 32, 43 and 46 are also connected to the steering control unit 41. The radiating elements 33, 44 and 47 are all located in quadrant A of the array antenna 11. For all the elements in the other three quadrants, a similar system is provided between the steering unit 41 and the respective modulators. All the elements in all four quadrants are connected to the steering unit 41 and the phase of the signal transmitted from each individual element, with reference to all other elements, is controlled by the steering unit 41, as described in U.S. Patent No. 3,238,528.

In a phased array antenna 11 having a great many elements, such elements preferably are equally spaced with respect to each other. If a signal of the same phase is applied to all the elements, the direction of the main beam will be broadside to the array at an angle θ=O, FIGURE 1. In FIGURE 3, the beam from each element would then be along the axis of the element. If the phase of the signal from the element 33 is equal to Ø, and the phase of the signal from the element 44 is equal to 2Ø, and the phase of the signal at the element 47 is equal to 3Ø, as established by the steering unit 41, the main beam from the antenna 11 will be in a direction dependent upon the phase angles. The phase relationship between any one element and all other elements in the array antenna 11 is the vector sum of the phase established by the steering unit 41 and the phase established by the modulators 12, 13, 14 and 16. For the three elements shown in FIGURE 3, the total phase of the signal at each element is equal to Øc + Ø, where Øc is a phase established by the modulator 12 and Ø is a phase of the individual elements as established by the steering unit 41.

A return signal received by one of the elements of the array antenna 11 is shown in FIGURE 6. Frequency processing in the form of pulse compression is a known procedure in operating a tracking radar system and is illustrated herein to operate on the pulse. Pulse compression is employed in radar where transmitted pulses are long in order to to obtain a resolution and acuracy of a short pulse while retaining the high power of a long pulse. A compression unit 42, leading to receiver 39, FIGURE 4, operates on the modulation of the received pulse 94 to compress the pulse to a much shorter one. FIGURE 6 shows both the received pulse 94 and the compressed pulse 96. The received signal, as well as the transmitted pulse, has a time frequency characteristic 95. In accordance with pulse compression techniques, the received pulse is passed through compression unit 42 which consists essentially of a filter which delays high frequencies more than low frequencies. As a result, the various frequency components are stacked one on top of the other in time, resulting in the compressed pulse 96. The pulse is compressed so that the main part of it lies within the time gate 97; some subsidiary parts may lie outside the gate. By way of example, the received pulse 94 of 10 microseconds duration may be compressed into a 0.1 microsecond gate 97.

If the target is not on the beam scan axis the received signal will be amplitude modulated. Modulation results in side bands spaced above and below the frequency $f_o = \omega_o / 2\pi$. Such a return signal envelope 48 is shown in FIGURE 7 with both the upper and lower side bands 49 and 50 related to the center frequency 48'. Side bands 49 and 50 cause early and late signals 51 and 52, respectively, to appear in the compressed wave 53 shown in FIGURE 7. The phase of the lower side band in the early compressed pulse 51 contains information relative to the target angle, i.e., the angle between the target direction and the scan axis of the conical beam.

FIGURE 8 illustrates in greater detail the receiver 39 of FIGURE 4. In FIGURE 8 the conopulse oscillator 18 is connected by channel 18a to a phase comparison unit 54 and by way of channel 18b to a phase comparison unit 55. The pulse compression unit 42 has channel 31a leading thereto by means of which the received signal is applied to the pulse compressor 42. The compressed output signal containing pulses 51-53 of FIGURE 7 is applied by way of channel 42a to a gate 42b. The gate 42b

passes that portion of the compressed pulse from unit 42 to each of three comparison circuits 54, 55 and 56 for the duration of the time gate 60. The gate 42c passes that portion of the compressed pulse lying within time gate 61 to the amplitude comparison unit 65 only. The outputs of the comparison circuits 54-56 are applied to the steering unit 41 as indicated by the connections from the receiver 39 shown in FIGURE 4. Thus, the phase of the lower side band signal is compared with the two quadrature phase outputs from the pulse oscillator 18 by means of the phase comparison circuits 54 and 55, respectively. The output signal from the phase comparison circuit 54 is representative of a phase shift by rows of elements in the antenna array 11 that is necessary to center the target in the beam. The output signal from the phase comparison circuit 55 is representative of the column phase shift of the elements of the antenna 11. Thus, the outputs of the circuits 54 and 55 are representative of the target angle relative to the scan axis of the beam.

By amplitude comparison of the center compressed pulse 53, FIGURE 7, with the lower side band pulse 51 in a comparison circuit 56, an angular lead signal is produced. The output of the amplitude comparison circuit 56 is connected to the steering unit 41 where it is utilized, like lead signals produced in prior systems, for improving the tracking acuracy.

Thus for a target directly on the scan axis of the conical beam, there is uniform illumination during the transmitted expanded pulse interval. As a result, only one receive or chirp frequency component f_o is present as indicated in FIGURE 6. Such a return signal when compressed is characterized by a single pulse 46, FIGURE 6, which will be present in the readout operation of the target video signal.

As above noted, if the target is displaced from the scan axis of the conical beam, the received amplitude envelope will be amplitude modulated at a prescribed frequency corresponding with the frequency of the conopulse oscillator 18. Where the conopulse oscillator has a frequency of 1 megacycle, then the upper and lower side bands will be spaced $\pm$ 1 megacycle from the frequency f_o. As indicated in FIGURE 7 where the received pulse gate length is 10 microseconds, there are 10 cycles of amplitude modulation on the received pulse 48. Because of this modulation, the signal at the output of the pulse compressor 42 includes, along with the center pulse 53, the lower and upper side band pulses 52 and 51, FIGURE 7. By establishing the early gate 60 centered on the lower side band pulse 51 the first range readout signal from the lower side band is produced. The phase of this first range readout signal is indicative of the angle between the scan axis of the beam and the target. Thus the phase comparison in units 54 and 55 between pulse 51 and the outputs of the conopulse oscillator 18 will produce signals at the outputs of units 54 and 55, respectively, representative of row and column phase shifts necessary for aligning the beam with the target.

By comparing the amplitudes of the pulses 51 and 53 which appear in gates 60 and 61, the angle lead is determined for aiding in tracking the target.

The location of the pulse 53 in the compressed return signal is carried out in accordance with well-known procedures which are generally designated as early gate-late gate tracking, as described in INTRODUCTION TO RADAR SYSTEMS, Skolnik, McGraw-Hill, 1962, pages 189, 190. Further, where the conopulse oscillator 18 employs a 1.0 megacycle output, the lower side band pulse 51 of FIGURE 7 will always be centered one microsecond earlier than the center of compressed pulse 53. Thus the gates 42b and 42c will be controlled in accordance with the known early gate-late gate tracking radar techniques with the time relations indicated in FIGURE 7.

While the foregoing description has been based upon the operation of a phased array antenna having a great number of radiating elements, it wil be appreciated that a within pulse conical scan may be generated and utilized by a system in which the relative phases of excitation signals are controlled for application to only three or four radiating elements mounted in spaced-apart relation within a given reflector which may be positionally adjusted to control the normal beam axis. In such case, as well as in the operation of a phased array antenna composed of many radiating elements, a conical beam is produced within the period of each transmit pulse of the radar. Such a system is readly distinguishable from systems employing conical scan operations wherein a reflector is rotated and a pulse is radiated at each of a plurality of antenna positions such that a cone is scanned only by use of a plurality of transmit pulses. In the conopulse radar system described heren, the phase of the signals applied to the antenna elements are so controlled by the conopulse oscillator that during the period of each transmit pulse of each antenna, the beam completes a conical path. Because of the characteristics of the phased array radar, the present invention is particularly adaptable thereto but it should be understood that it is not limited to a phased array radar of the type shown in FIGURE 1. More particularly, only three dipoles or three horns

may be employed. In such case they will be excited by signals that are 120° out of phase. Alternatively, a single radiator may be employed in place of each of the multi-element sectors A-D of FIGURE 1 and each may be excited as in FIGURE 1 for scanning during the period of each transmit pulse.

In FIGURE 1, two switches 80 and 81 are provided in the channels leading from oscillator 18. It will now be seen that if one of the two switches is opened line scanning will be accomplished within transmit pulse period. One scan direction will be selected by opening switch 80 with switch 81 closed and a perpendicular direction will be selected with switch 80 closed and switch 81 open.

Thus, while in the above description of the invention reference is made to conopulse operation which implies a rotational scan, the within pulse scan operation of the invention is not limited to rotational scanning but may be employed with line scanning. The preferred mode of operation in any case involves changing the beam direction during the transmit pulse period and extracting target position information from the return signal.

Having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art and it is intended to cover such modifications as fall within the scope of the appended claims.

WHAT WE CLAIM IS:

1. A radar system having a multi-element antenna and a first beam steering control means for individually establishing the phase of the signals transmitted from each element of said antenna to steer the antenna beam, a second control means for modifying the phase of the signals established by said first control means to steer the antenna beam, within the time duration of each transmit pulse, completely over a predetermined scan trajectory relative to a scan axis for production of return signals from targets which, when displaced from the scan axis, are amplitude modulated, and receiver means connected to the said second control means and to said elements to utilize the return signal to produce a signal dependent upon said amplitude modulation which is representative of the relation between the scan axis and the target direction.

2. A radar system as claimed in Claim 1, wherein the said elements are at least three in number, and in which the predetermined scan trajectory is conical.

3. A radar system, as claimed in Claim 2, wherein the said elements are energized by a transmit reference oscillator, wherein the beam steering control means is operable to establish at each element a predetermined phase relation in the signal transmitted from said element relative to the phase of the signal transmitted from others of said elements, and in which the second control means includes means for phase modulating the signal from said transmit reference oscillator by sections of said array to cause the beam steering control means to scan the said beam over a conical path during each transmit pulse period.

4. A radar system as claimed in Claim 3, wherein a phase modulator is connected at one input to the output of the transmit reference oscillator and a further scan control oscillator is connected to supply a modulating signal to a second input of said modulator at a frequency and amplitude lower than the respective frequency and amplitude of the signal from said transmit reference oscillator.

5. A radar sytem as claimed in Claim 3, wherein the antenna is a phased array antenna having like groups of radiating elements lying in each of four quadrants, wherein the four quadrants are connected to first and second phase modulators for applying the modulated output of said transmit reference oscillator to signal channels leading to the elements of first and third quadrants respectively of said antena and third and fourth phase modulators for applying the modulated output of said transmit reference oscillator to signal channels leading to the elements of the second and fourth quadrants respectively of said antenna, and a scan control oscillator connected to each of the four modulators for modulating the signal of said transmit reference oscillator, thereby modifying by quadrants the phase of the signal established by the beam steering control means and transmitted from each element of said antenna to produce at least once during each transmit pulse period a conical span of the beam from said array.

6. A radar system as claimed in any preceding claim, wherein the second control means is operable to modify the phase of the signals established by the beam steering control means and transmitted by said elements so that the antenna beam traverses a plurality of scan trajectories during each transmission pulse period.

7. A radar system as claimed in any preceding claim, wherein the return signal is passed through a pulse compression unit prior to processing the return signal to extract target location information therefrom.

8. A radar system as claimed in Claim 7, wherein the pulse compression unit is adapted to produce a centre frequency pulse and upper and lower side band pulses in response to a target return signal indicat-

may be employed. In such case they will be excited by signals that are 120° out of phase. Alternatively, a single radiator may be employed in place of each of the multi-element sectors A-D of FIGURE 1 and each may be excited as in FIGURE 1 for scanning during the period of each transmit pulse.

In FIGURE 1, two switches 80 and 81 are provided in the channels leading from oscillator 18. It will now be seen that if one of the two switches is opened line scanning will be accomplished within transmit pulse period. One scan direction will be selected by opening switch 80 with switch 81 closed and a perpendicular direction will be selected with switch 80 closed and switch 81 open.

Thus, while in the above description of the invention reference is made to conopulse operation which implies a rotational scan, the within pulse scan operation of the invention is not limited to rotational scanning but may be employed with line scanning. The preferred mode of operation in any case involves changing the beam direction during the transmit pulse period and extracting target position information from the return signal.

Having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art and it is intended to cover such modifications as fall within the scope of the appended claims.

WHAT WE CLAIM IS:

1. A radar system having a multi-element antenna and a first beam steering control means for individually establishing the phase of the signals transmitted from each element of said antenna to steer the antenna beam, a second control means for modifying the phase of the signals established by said first control means to steer the antenna beam, within the time duration of each transmit pulse, completely over a predetermined scan trajectory relative to a scan axis for production of return signals from targets which, when displaced from the scan axis, are amplitude modulated, and receiver means connected to the said second control means and to said elements to utilize the return signal to produce a signal dependent upon said amplitude modulation which is representative of the relation between the scan axis and the target direction.

2. A radar system as claimed in Claim 1, wherein the said elements are at least three in number, and in which the predetermined scan trajectory is conical.

3. A radar system, as claimed in Claim 2, wherein the said elements are energized by a transmit reference oscillator, wherein the beam steering control means is operable to establish at each element a predetermined phase relation in the signal transmitted from said element relative to the phase of the signal transmitted from others of said elements, and in which the second control means includes means for phase modulating the signal from said transmit reference oscillator by sections of said array to cause the beam steering control means to scan the said beam over a conical path during each transmit pulse period.

4. A radar system as claimed in Claim 3. wherein a phase modulator is connected at one input to the output of the transmit reference oscillator and a further scan control oscillator is connected to supply a modulating signal to a second input of said modulator at a frequency and amplitude lower than the respective frequency and amplitude of the signal from said transmit reference oscillator.

5. A radar sytem as claimed in Claim 3, wherein the antenna is a phased array antenna having like groups of radiating elements lying in each of four quadrants, wherein the four quadrants are connected to first and second phase modulators for applying the modulated output of said transmit reference oscillator to signal channels leading to the elements of first and third quadrants respectively of said antena and third and fourth phase modulators for applying the modulated output of said transmit reference oscillator to signal channels leading to the elements of the second and fourth quadrants respectively of said antenna, and a scan control oscillator connected to each of the four modulators for modulating the signal of said transmit reference oscillator, thereby modifying by quadrants the phase of the signal established by the beam steering control means and transmitted from each element of said antenna to produce at least once during each transmit pulse period a conical span of the beam from said array.

6. A radar system as claimed in any preceding claim, wherein the second control means is operable to modify the phase of the signals established by the beam steering control means and transmitted by said elements so that the antenna beam traverses a plurality of scan trajectories during each transmission pulse period.

7. A radar system as claimed in any preceding claim, wherein the return signal is passed through a pulse compression unit prior to processing the return signal to extract target location information therefrom.

8. A radar system as claimed in Claim 7, wherein the pulse compression unit is adapted to produce a centre frequency pulse and upper and lower side band pulses in response to a target return signal indicat-

ing displacement of the target from the scan axis, and including amplitude comparison means for comparing the amplitude of the centre frequency pulse and that of the lower side band pulse to indicate the angle lead of the target direction from the scan axis.

9. A radar system as claimed in Claim 7 or Claim 8, in which the output of the pulse compression unit is connected to a phase comparator means connected to said second control means for determining the target angle relative to the scan axis.

10. A radar system as claimed in any preceding claim, wherein the antenna has a like plurality of radiating elements in different antenna sections, and wherein the phase angles of the signals for all elements in a given section of the antenna are modified by an identical amount.

11. A radar system having a multi-element antenna substantially as described herein with reference to and as illustrated by the accompanying drawings.

ABEL & IMRAY,
Chartered Patent Agents,
Northumberland House,
303-306 High Holborn,
London W.C.1.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1971
Published at the Patent Office, 25 Southampton Buildings, London WC2A 1AY from which copies may be obtained.