

April 8, 1969

J. J. FLING ET AL

3,438,035

PENCIL BEAM FREQUENCY/PHASE SCANNING SYSTEM

Filed Aug. 8, 1966

Sheet 1 of 3

FIG. 1.

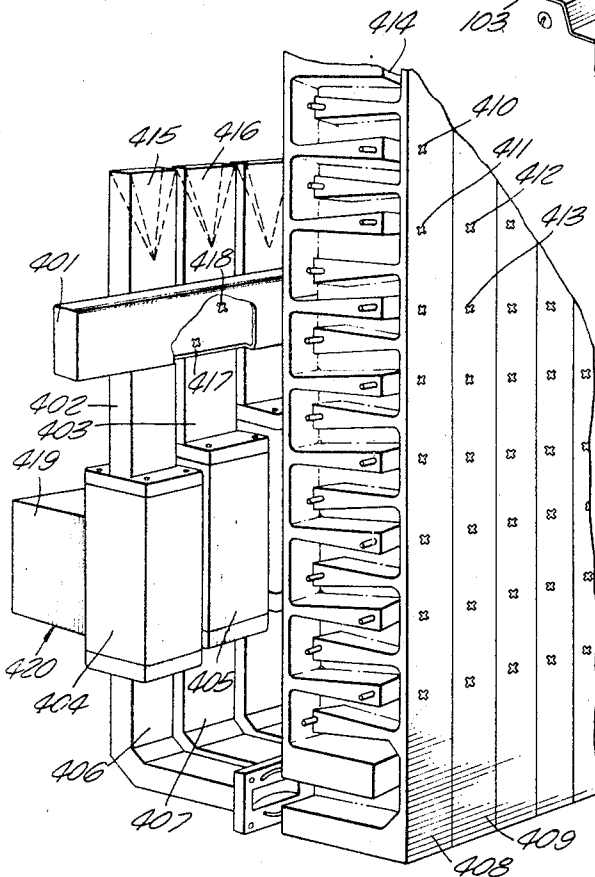
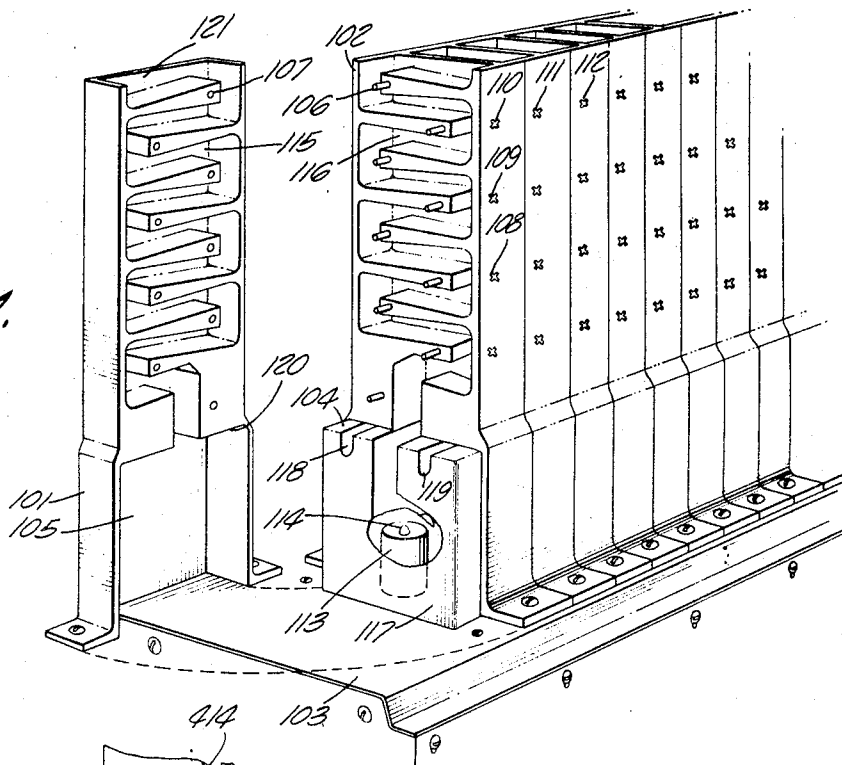


FIG. 4.

INVENTORS

JOHN J. FLING

SHIRLEY L. HOWARD

FREDERICK M. WEIL

BY

William T. O'Neil

AGENT

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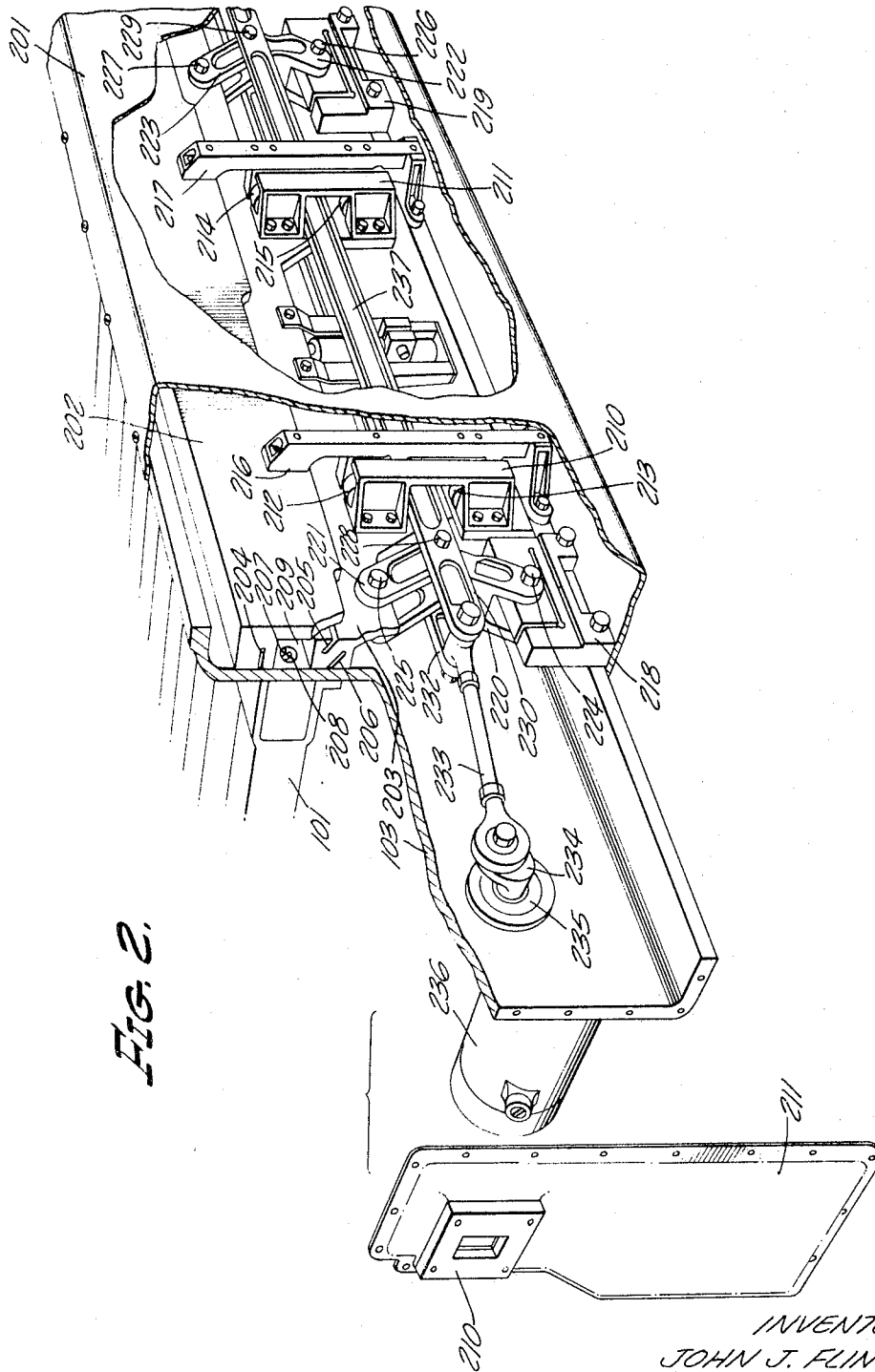
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SHIRLEY L. HOWARD
FREDERICK M. WEIL
BY
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AGENT

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Sheet 3 of 3

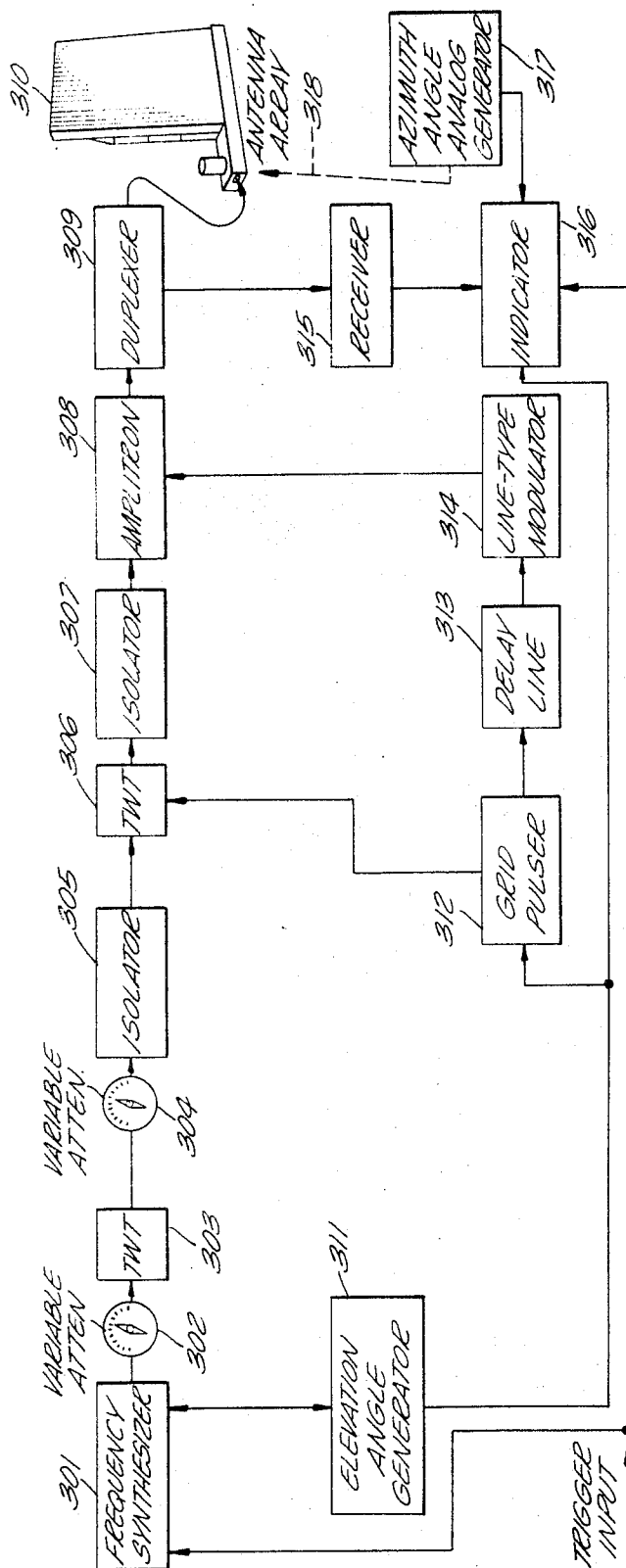


FIG. 3.

INVENTORS
 JOHN J. FLING
 SHIRLY L. HOWARD
 FREDERICK M. WEIL
 BY
William T. O'Neil
 AGENT

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3,438,035 PENCIL BEAM FREQUENCY/PHASE SCANNING SYSTEM

John J. Fling, Malibu, Shirley L. Howard, Rolling Hills Estates, and Frederick M. Weil, La Canada, Calif., assignors to International Telephone and Telegraph Corporation, a corporation of Delaware

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Int. Cl. H04b 7/10

U.S. Cl. 343—100

8 Claims

ABSTRACT OF THE DISCLOSURE

A two dimensional antenna array and scanning system particularly adapted to instrumentation in the micro-wave regions are illustrated and described.

A number of radiating elements are arranged in columns and rows in a planar array to develop a directional beam relatively narrow in each of first and second angular space coordinates. The elements in each column are distributed along a separate transmission line feed, and these column transmission lines are driven from successive points along a waveguide acting as a phase distributor. The phase distributor waveguide has one movable wall which is mechanically moved to vary the *a* dimension of the guide. The resulting redistribution of energy phase relationships along the phase distributor waveguide modifies the relative phases at the said successive points from which the column transmission lines are energized. The result is scanning of the beam as a function of the aforementioned *a* dimension variations in the direction of the rows (first space coordinate). Variations in the frequency of energization of the system produce inertialess scanning in the columnar direction (second space coordinate). The columnar transmission lines are folded into a serpentine shape to lengthen the electrical feed path between radiators while keeping the spacings along the aperture to smaller values.

This invention relates to radar scanning systems. More particularly, this invention relates to radar apparatus for transmitting a pencil beam of electromagnetic energy which may be rapidly scanned in two dimensions such as elevation and azimuth.

Although the device of the present invention is not limited to any particular scan program, it is most adapted to the scanning of a pencil beam for transmitting and receiving within a solid angular sector such as is commonly undertaken in connection with GCA (Ground Controlled Approach) radar systems (i.e., where the scan program in one coordinate can be a relatively slow repetitive program such as a sinusoidal function).

In its form most useful for GCA or similar purposes, the invention is implemented in the form of a two dimensional array arranged with a plurality of individual radiating elements disposed in vertical and horizontal rows. In one coordinate, normally elevation, the array is constructed to be frequency sensitive such that the elevation angle of the pencil beam is a function of the microwave frequency transmitted or being received. Each vertical row of radiating elements receives common excitation from spaced points along a waveguide transmission line formed into a "serpentine" for reasons to be evident as the description proceeds. The plurality of "serpentes" is horizontally stacked such that the radiating elements form spaced horizontal rows according to a predetermined plan as well as the aforementioned vertical rows of radiating elements. Thus each horizontal row of radiators contains one correspondingly positioned radiating element from each "serpentine."

In this arrangement, the "serpentes" are fed from successive points along a variable width waveguide phase distributor assembly, according to one embodiment of the present invention.

The said phase distributor assembly with its variable guide width (in the *a* dimension) feature, serves as a variable microwave energy phase distributor, such that the phase difference in energy fed to succeeding "serpentes" varies as the said guide width is varied. Thus, the entire array may be thought of as being phase scanned in the azimuth polar coordinate, whereas it is frequency scanned in the elevation polar coordinate. Thus the angle of the pencil beam in the azimuth coordinate is a function of the guide width of the said waveguide distributor assembly. In elevation the frequency variations themselves produce corresponding phase differences in energy progressively between succeeding radiating elements disposed vertically along said "serpentes." Accordingly, the angle of the pencil beam in elevation is a function of the frequency received or transmitted.

In the prior art, systems involving the use of a waveguide "serpentine" with spaced radiating elements to obtain a frequency scanning array are known per se. U.S. Patent No. 3,039,097 illustrates and describes such a system in simple form. Other systems are also known which combine the frequency scanning technique of aforementioned U.S. patent with phase control means to excite a plurality of elements in the other coordinate which form a two dimensional array, to produce phase scanning. Characteristically however, such systems have involved the use of complex frequency/phase logic with multiple frequency generators, mixers, multipliers, and sum and difference circuits, to effect the desired phase control.

In the present invention, a method of phase control through the use of the said variable guide width assembly is introduced in order to greatly reduce the complexity of this aspect of the scanning mechanism. The present invention moreover, provides stability and comparatively low cost instrumentation, in a system where the beam positioning capability in the phase control coordinate is programmed in a relatively simple smoothly varying manner.

Accordingly, it may be said that the general objective of the present invention is the provision of a comparatively simple, highly stable, reliable, and relatively inexpensive two-coordinate pencil beam scanning radar system.

In describing the present invention, drawings are presented as follows:

FIGURE 1 is a partially exploded view of an assembly of "serpentes" and radiators forming the two-dimensional array.

FIGURE 2 is a mechanism detail showing the construction of the variable waveguide width phase distributor assembly.

FIGURE 3 is a block diagram of a typical system in accordance with the present invention.

FIGURE 4 illustrates an alternative phase distributor configuration for use with the present invention.

Referring now to FIGURE 1, an assembly of the waveguide serpentine is shown. It will be readily apparent from FIGURE 1 that each of the stacked serpentes is composed of two sections of which 101 and 102 are typical. In the closed position a series of pins (of which 106 is typical) in the section 102 engage corresponding holes such as 107 in section 101. Well known mechanical means which are not a part of the present invention are employed to insure tight contact between the sections 101 and 102 in the assembled condition.

Each of the typical serpentine half-sections as 101 and 102 is typically formed from an accurately machined

block preferably of aluminum alloy or other conductive and machinable metal. The matching serpentine shaped groups, typically 115 and 116, are then readily mated together to form the serpentine shape fully enclosed waveguide path. Thus, the entire stack of serpentine forms a mechanically rigid assembly readily hardened against the most unfavorable environmental conditions.

In the particular design depicted in FIGURE 1, the section 102 includes an integral boss 117 as part of its body. As this boss or projection 117 fits into the cavity 105 on the section 101, some tolerance relief and improved performance is achieved through the inclusion of choke slots 118 and 119, as shown. In this way, an electrically leak-proof fit between surfaces 104 and 120 is achieved.

Although not shown in FIGURE 1, it is to be understood that the tops of the individual serpentes, as for example 121, must be suitably terminated electrically in accordance with known criteria.

A portion of the boss 117 is shown slightly cut-away for clarity and illustrating the coaxial feed which connects each of the serpentes to a selected point along the phase distributor assembly below.

Opening 113 is the coaxial feed outer conductor formed by boring a continuous opening from the said phase distributor channel below into the beginning of the serpentine waveguide itself at 122. The center conductor of this coaxial feed or transition is illustrated at 114. The design of this coaxial coupler follows the known criteria for waveguide to coaxial to waveguide transmission lines.

The said phase distributor assembly, the top outline of which shows at 103, is shown in detail in FIGURE 2.

Radiating elements 108 through 112 are typical of the entire array. These are depicted as cross-slots opened through the serpentine assembly wall. It will be noted that radiating element 108, 109, and 110 are asymmetrically located with respect to the vertical center line of each of the vertically stacked serpentine assemblies. The purpose of this asymmetrical location in this particular design concerns the radiation of circularly polarized microwave energy by the entire array. The criteria governing the placement of such radiating elements in the guidewall to produce circularly polarized radiant energy are known in the art. It will be seen that all radiating elements in the same vertical row as 108, 109, and 110 receive energy from the same first point in the phase distributor assembly below. The same may be said of all radiating elements in the same vertical row as 111 from the same second phase distributor point. Also all elements in the same vertical row as 112 receive energy from their own particular successive point along the phase distributor assembly below, and so on throughout the array.

As has been previously stated, elevation scanning of the resultant pencil beam formed by the array of FIGURE 1 is effected by changing the frequency which excites the entire array. The pointing angle of a linear traveling wave array such as illustrated in FIGURE 1 scans as the radio frequency is varied, but the specific variation of beam pointing angle as a function of frequency change is, of course, dependent upon the physical geometry of the array. The frequency scan sensitivity (i.e., dx/df) of such a linear array using a single straight waveguide is not sufficient to achieve a practical scan sensitivity without exceeding the 5 to 10% frequency variation which the various components could be expected to tolerate in terms of bandwidth in a practical design. In order to increase the frequency sensitivity of the array to a value appropriate for the combination of required scan angle and available bandwidth, the length of transmission line between successive radiators must be effectively increased to cause the radio frequency phase delay between elements to be significantly greater than the phase delay due to the mere physical spacing of the radiators along the axis of the array. This increase in transmission line path length has been achieved by using a line which is physically longer than the desired antenna

aperture. Hence the folding of the individual vertical waveguide feeds into the serpentine configuration.

Referring now to FIGURE 2, the mechanical and structural details of the phase distributor assembly will be discussed.

The so called phase distributor assembly as an element of the combination of the present invention is based on the principles of the so called "Delta α " scanner. Such scanners have been used in GCA (Ground Controlled Approach) radar equipments for many years. A basic description and theoretical discussion of the "Delta α " scanner principle per se appears in the Massachusetts Institute of Technology Radiation Lab Series, 1st ed., published by McGraw-Hill Publishing Company, and also in U.S. Patent No. 2,605,413. A particular reference is in connection with the AN/APQ-7 (Eagle), an air-borne radar device of the World War II era, in vol. 26, chapter 6, p. 185 et seq. U.S. Patents 2,596,113 and 2,596,966 describe mechanical improvements relating to such "Delta α " scanners as they were used in GCA equipment. It will be noted that both of the aforementioned United States patents show long strings of dipoles disposed along the length of the guide. The changes of energy phase distribution within the guide in the lengthwise dimension serve to cause a change in the direction of the directional beam thereby formed as a function of waveguide width in the so called α dimension.

In FIGURE 2, a series of coaxial probes located along the phase distributor guide length serves to couple energy into the several serpentine guides in substantially the same manner as coaxial probes are employed to feed the plural dipoles illustrated in the aforementioned two United States patents.

The view shown in FIGURE 2 is rotated 90° as compared to the pictorial aspect illustrated in FIGURE 1, and the cover 201 is shown cut-away to show the mechanism. Note the position of the end serpentine 101 in FIGURE 2. The typical coaxial probe arrangement is illustrated where the opening in the bulkhead 103 at 207 serves as the outer conductor and the pin 208 as the inner conductor. A structural piece 202 is held in place by bridging members such as 216 and 217, spaced along the length of the member 202. The moving member which serves to vary the so called α dimension is depicted at 203. As 203 is translated in the up-down direction, as viewed in FIGURE 2, the cross-sectional width of the waveguide chamber 209 is varied. Choke slots 204, 205, and 206 serve to substantially eliminate radio frequency leakage at the sliding surfaces, or where surfaces are subject to adjustment. The function of drive motor 236, bearing 235, crank 234, and arm 233 will be apparent for the purpose of imparting longitudinal motion to the drive bar 230 and its counterpart 232. A plurality of bars of which 220, 221, 222, and 223 are typical, provide the structure which serves the purpose of moving the member 203 while maintaining its parallelism with the walls of the waveguide opening 209. Rotational freedom is, of course, available at the pivot points such as 224, 225, 226, 227, 228, and 229. A shaft 237 constrained by a sleeve 231 serves to provide outside sensing of the change of waveguide width. Rollers mounted as shown at 212, 213, 214, and 215, maintain mechanical pressure against that portion of the member 203 which extends so as to engage the said rollers. Mounting blocks 218 and 219 afford means for making fine adjustment of the waveguide width variation by means of set screws (not shown). The shaft 237, together with the sleeve 231, is also capable of providing longitudinal constraint for the member 203 so that its motion is entirely in the up-down direction in the context of the pictorial aspect of FIGURE 2. The end plate 211 with the waveguide mounting plate 210 may represent either the input or output feed to the entire assembly, and may be thought of as being in similar form at the opposite end of the phase distribu-

tor waveguide for electrical termination connection purposes.

Referring now to FIGURE 3, this simplified block diagram will be seen to illustrate the manner in which the essential functional components of a system in accordance with the present invention may be instrumented. A frequency synthesizer 301 first generates a subharmonic of the variable frequency signal and then multiplies to reach the radio frequency which is intended to be supplied to the antenna array 310. This frequency generation may be self-programmed within 301 or may be controlled by the elevation analog-generator 311. If it is self-programmed, then the analog-generator 311 must be constructed to convert the frequency increments into an analog signal which is then used as an angle-scan control signal by the indicator 316. If the elevation analog generator 311 acts as the angle-scan programmer for elevation scan of the pencil beam of the present invention, frequency synthesizer 301 would then be adapted to accept the analog angle signals in either analog or digital form to control the frequency synthesizer accordingly. The synthesizer 301 would ordinarily be constructed with a bank of crystal controlled or other stable oscillators, each responsible to a significant digit of a digital elevation angle control signal from 311. With proper mixing and filtering the synthesizer 301 thus is capable of producing the desired sub-harmonic radio frequency signal according to a pre-determined frequency program.

It is to be understood that the frequency synthesizer 301 also includes the necessary radio frequency multipliers whereby the frequency of the sub-harmonic delivered by the bank of crystal oscillators is raised to the desired transmitting frequency to be supplied through the variable attenuator 302 to the traveling wave tube 303. The said variable attenuator 302 acts as a means of adjusting the power level for the traveling wave tube input and the said traveling wave tube 303 provides power amplification.

The variable attenuator 304 adjusts the power level input to the traveling wave tube 306 through the isolator 305 to prevent variable loading of 303. Additional power amplification in 306 produces a sufficient power level to drive the amplatron 308 through the isolator 307. A synchronizing trigger input provides timing control for the grid pulser 312 and also a "clock" pulse to the frequency synthesizer 301. Traveling wave tube 303, since it operates at a comparatively low power level, is permitted to operate continuously, however, in order to preserve peak power handling capability without exceeding average power handling capability, the traveling wave tube 306 is pulsed into operation synchronously during each transmitted pulse. The high power level amplifier 308 is similarly pulsed by a line type modulator 314 driven from grid pulser 312 through an appropriate delay line 313. The output of the amplatron power amplifier 308 is then fed to the phase distributor portion of the antenna assembly, i.e., at 210 in FIGURE 2 through duplexer 309. The duplexer 309 serves the ordinary transmit-receive function so that transmitter power from 308 is isolated from receiver 315 during transmit and received signals coming from the antenna array 310 are directed through the duplexer 309 to the receiver 313 without substantial division of received power into the microwave circuitry of 308. The azimuth angle analog-generator 317 provides the electrical analog of the mechanical motion of the shaft 237 on FIGURE 2, descriptive of the variations of the so-called α dimension of the phase distributor guide. The output of angle generator 317 in the instant example is representative of the azimuth angle of the pencil beam formed by the array 310, whereas a signal from the elevation angle generator 311 is representative of the instantaneous elevation angle of the said pencil beam. Since it is supplied both of these angle signals, the indicator 316 is readily adapted to present in separate displays, signals as a function of range and elevation and also signals as a function of range and

azimuth. A system trigger is shown supplied to the indicator and frequency synthesizer for the ordinary transmitter to indicator synchronization. The precise configuration of the indicator 316 is not a part of this invention since the system is adapted to the use of any of several well known prior art approaches involving separate cathode-ray tubes or a dual beam cathode-ray tube.

The output 318 shown dotted from the Azimuth Angle Analog Generator is pertinent only in respect to the embodiment of FIGURE 4 and will be explained in connection therewith.

Referring now to FIGURE 4, the simplified diagram of an alternative method and structure for producing the phase scan responsible for direction of the pencil beam in azimuth is shown. As in the embodiment represented by FIGURES 1 and 2, a frequency varying signal for frequency scanning in elevation is supplied to the waveguide 401 for transmitting purposes. In discussing FIGURE 4, the descriptive and operational references will be confined to the transmitting situation, it being fully appreciated that the embodiment of FIGURE 4 is as reciprocal in respect to transmitting or receiving (subject to certain limitations to be described later) as is the embodiment represented by FIGURES 1 and 2. A plurality of intermediate feed waveguides, such as 402 and 403, are fed in parallel from the waveguide 401. Coupling slots, of which 417 and 418 are typical, produce the necessary guide-to-guide energy coupling according to well known principles. Each of the typical intermediate feed waveguides 402 and 403 has a corresponding stub and resistive termination 415 and 416, respectively, in order to maintain impedance match and desired standing wave ratio conditions. A termination of each serpentine as at 414 is also understood. It will also be noted from FIGURE 4 that each of the said intermediate waveguide feeds, such as 402 and 403, feeds a corresponding ferrite-type phase shifter (404 and 405 respectively), and the outputs of the said ferrite microwave phase shifters are fed by corresponding waveguide sections 406 and 407 into the serpentine bank. Only the 406 and 407 waveguides which are associated with the serpentes 408 and 409 respectively will be discussed, although it is to be understood that the structure is duplicated for each successive serpentine in the array. The beginning end serpentine 408 as shown is comparable to the serpentine 102 in FIGURE 1 and is similarly illustrated in a cut-away condition for clarity.

The microwave phase shifters 404 and 405 are available as components designed and manufactured to introduce pre-determined delays as a function of control signals. In FIGURE 4, these phase shifters 404 and 405 are preferably of the latching digital ferrite type. Each such phase shifter receives a parallel binary code signal from a control box 419, which in turn would be controlled by an azimuth angle programmer operating in lieu of the azimuth angle analog-generator 317 of FIGURE 3, without any connection to the antenna array 310. The output 318 from such an azimuth programmer is then a parallel digital code signal at input 420 to each of the ferrite control boxes 319 which in turn control the phase shift provided by each ferrite shifter (typically 404 and 405). Such a digital azimuth control program is also appropriately interpreted by the indicator 316 of FIGURE 3. The spacing between adjacent serpentine slots such as 410 and 411 in serpentine 408 and between 412 and 413 in serpentine 409 is selected according to the same criteria as prevailed in connection with radiator slots 109 and 110, for example, in FIGURE 1. In accordance with the parallel multi-digit control signal received by each of the said digital ferrite phase shifters successively greater or lesser delays are introduced by these devices depending upon which end of the horizontal dimension of the array is selected as a starting point. Thus the phase delay program exhibited among the stacked serpentes in a horizontal direction effects substantially the same phase control effect as obtained by the variable guide-

width phase distributor assembly in the embodiment of FIGURES 1 and 2.

Table 1, following, lists the significant design parameters and requirements for each of the digital phase shifter assemblies such as 404 and 405 et seq. for a practical operating system.

TABLE I

Definition:	Requirements
Number of bits -----	5
Most significant bit (phase shift) degrees---	180
Least significant bit (phase shift) do----	11¼
Frequency range -----gHz---	8.975-9.19
Peak power -----kw---	1
Average power -----w---	10
RF pulse width -----µsec---	0.2
Maximum time to switch all bits µsec---	1
Maximum switching rate -----kc---	8
Input/output VSWR -----max---	1.2
Insertion loss -----max---	1
Operational temperature range ---° C---	75±10
Dimensions---	
Maximum width -----inch---	1.060
Height -----	Unrestricted

There is one important aspect in which latching ferrite phase shifters differ basically from most other microwave devices; ferrite phase shifters are in a sense non-reciprocal. Thus, a ferrite which introduces a particular phase shift into a wave traveling in one direction will introduce a different phase shift into a wave traveling in the opposite direction. In terms of the ferrite scanned radar antenna, as depicted in FIGURE 4, this means that, unless the ferrites are switched between the transmit and receive mode of the radar system, the antenna will be unable to receive its own target echoes since the signal contributions from the individual radiators will not be added in the correct phase. Fortunately, the switching program required to establish the correct phase relationships for one direction for a given setting equals the delay in the direction. This is the result of the relationships in a phase shifter for its alternate settings. The total phase delay in one direction for a given setting equals the delay in the other direction for the other setting, and vice versa. Hence, to change between transmit and receive, all that is necessary is to switch every ferrite to its alternate state of magnetization and complete reciprocity is restored. To achieve this in a binary control system as applied to 404, 405, etc., requires only that all zeroes are replaced by ones and all ones by zeroes.

Digital ferrite phase shifters have the advantage of low-loss operation, relative ease and accuracy of phase shift control, and compactness. They are inherently capable of a higher degree of phase shift accuracy as compared to analog ferrite phase shifters which are also known per se in the art.

At this point in the discussion it will be realized that the embodiment or variation described in FIGURE 4 is capable of a more rapid and more complex (even random) programming of azimuth pencil beam steering. The embodiment depicted in FIGURES 1 and 2 however, has the advantage of electronic simplicity and long time repeatability, and is readily adaptable where the azimuth scan program is fixed and conforms to a regular pattern such as a sine wave motion as a function of real time. The mechanism of FIGURE 2, as depicted, will be recognized as producing essentially simple harmonic motion of the member 203 and therefore would produce a corresponding azimuth scan program.

It will be noted from the exploded serpentine views of FIGURES 1 and 4 that the waveguide configuration generated within the serpentine assembly may be referred to as a dovetail type of serpentine.

The invention is, of course, not restricted to the particular mechanical details of the serpentine of itself. The

simplest type of serpentine is a folded or snake-feed type of waveguide in which 180° bends or elbows are separated by short intermediate lengths of waveguide. A so-called inter-digital serpentine detail is also possible, and in this configuration all angles in the waveguide serpentine path are 90° angles. Such inter-digital waveguide assemblies are so named because of their physical similarity to inter-digital waveguide line filters. The dimensions of the bends would be adjusted for minimum voltage standing wave ratio (VSWR) at a desired frequency or band of frequencies without the use of additional matching irises.

For further information relative to the design of linear arrays, such as employed in the present invention, the following background data is presented for clarification.

The radio frequency wave front leaving a linear array will change its direction only when a change is introduced into the phase distribution along the array aperture. This is equally true for any kind of electronic scanning, the different scan methods being diverse ways of introducing the necessary phase changes into the antenna. Consequently, for array design, the instantaneous beam angles in either coordinate resulting from either the frequency scan contemplated for elevation in the present invention or the mechanically effected phase changes of the azimuth scan system, follow the same fundamental laws. Accordingly, it is possible to express the relationship between scan angle and other system parameters in a single relatively simple equation as follows:

$$\sin x = \frac{s}{d} \sqrt{1 - \left(\frac{c}{2af}\right)^2} - \frac{c}{fd} \left(\frac{\Delta\psi}{2\pi} + \eta\right)$$

Equation 1

wherein the parameters are defined as follows:

x is the scan angle measured in a plane containing the array axis. It is an angle formed by the R-F wave front and the axis of the array, or by the direction of radiation and the array normal. Positive angles are measured from the array normal toward the load end, negative angles from the array normal toward the input end of the array.

d is the distance between individual neighboring radiators measured along the array axis. There are some limitations to the values which d can assume besides obvious physical ones—depending on whether grating lobes are permissible and, if so, to what extent. If grating lobes must be avoided, d must comply with the following inequality:

$$d < \frac{\lambda_{\min}}{1 + |\sin x_{\max}|}$$

Equation 2

where:

$\lambda_{\min}$ —shortest wavelength,

$x_{\max}$ —largest scan angle,

the bars indicate absolute magnitude regardless of sign.

s is the spacing of the individual neighboring radiators measured along the center line of the waveguide.

c is the velocity of propagation in air.

a is the waveguide width.

f is the radio frequency (in cycles/second).

$\Delta\psi$ is the phase shift (in radians) introduced between neighboring radiators by means other than the length of the connecting transmission line. This includes discrete phase shifting elements as well as other expedients like reversed radiators. Dipole reversal or reversal of slot inclination, for instance, introduces a phase shift of 180° or π radians.

n , a dimensionless parameter, is a positive integer indicating the number of full wavelengths in the guide between successive elements at beam normal. A certain connection between n and d is to be noted. If d complies with Equation 2, only one value of n exists which results in real values (between ± 1) for $\sin x$ within the specified range of scan variables. For a design permitting grating lobes, the values of n which will result in real values

for sin x indicate the number and directions of all grating lobes.

Table 2 below shows the values used in a preliminary design for the two alternative azimuth scan embodiments with the elevation frequency scan design common to both. It should be pointed out again that the beam angles are measured in a plane containing the axis of the array involved.

TABLE 2

Parameters	Elevation	Δa (FIGURE 2 scanner)	Figure 4 phase scanner
s-----	4. 1675	0. 891	1. 065
d-----	0. 8695	0. 891	1. 065
a-----	0. 8505	1. 2495-723	0. 8205
f (mHz)-----	8, 975-9, 190	8, 975-9, 190	8, 975-9, 190
$\Delta\psi$ -----	0	π	$\pi-(-1. 112-+1. 143)$
n-----	2	0	0

The face of the array can readily be protected by a sealed radome to avoid dirt and moisture collection in the serpentines through the cross slot radiators. Such a simple expedient as placing a thin low loss plastic tape over the slots could also provide such protection.

The radiators themselves are convenient in the form of slots, especially where circular polarization is required, however, the use of individual dipoles seated in the serpentines is entirely possible in the manner of previously mentioned U.S. Patents Nos. 2,596,113 or 2,596,966.

The serpentines, although preferred in the present invention for mechanical reasons, could be replaced by helical or other shaped lines which provide the required length of waveguide between adjacent radiators. Bend radii within the serpentine may be 180° or may be somewhat greater, resulting in a more compact or "squeezed" serpentine. Bend radii less than 180° would effect spreading out of the serpentine line, an expedient also possible for a particular array design.

Although the description of the variable frequency generating means illustrated is based on a practical system for high accuracy operation, it should be understood that any means for producing the variable frequency microwave energy would effect the same results insofar as the scanning of the antenna system is concerned.

Other modifications and variations on the embodiments of the present invention will of course suggest themselves to those skilled in the art. It is not the intention of applicants that they should be limited to the specific instrumentations shown, since the drawings and description are intended as only illustrative and typical.

What is claimed is:

1. A system for receiving, radiating and scanning a directive beam of electromagnetic energy comprising: an array of antenna elements arranged in a plurality of rows and columns, said elements being disposed substantially in a single plane thereby to produce a directive beam generally broadside to said plane; a plurality of transmission lines, one such line for each of said columns, said antenna elements in each of said columns being fed successively at intervals by and along the length of a corresponding one of said transmission lines; phase distribution means comprising a variable a dimension waveguide for feeding said transmission lines in a phase relationship which varies incrementally from line to line; phase control means coupled to said phase distribution means for varying said incremental phase relationship by physically varying said variable a dimension, thereby to vary the angle of said directive beam in a first angular coordinate; and means for energizing said phase distribution means with variable frequency radio frequency energy thereby to change the phase relationship of excitation of said antenna elements along said transmission lines and consequently to vary the angle of said directive beam in a second angular coordinate.

2. An antenna system including a planar array for radiating and scanning a directive beam of electromag-

netic energy in two orthogonal coordinates through a predetermined volume of space comprising: a first waveguide section having a and b cross-sectional dimensions; a plurality of energy coupling means distributed at predetermined locations along the length of said first waveguide section; a corresponding plurality of second waveguide sections coupled one each to one of said energy coupling means, each of said second waveguide sections having a plurality of radiating means at predetermined locations along its length, each of said second waveguide sections being formed in a manner so as to cause all of said radiating means in said second waveguides to fall in rows and columns in the plane of said array and be directed to radiate in substantially the same direction, thereby to form a multi-element two dimensional array; means connected to energize said first waveguide with radio frequency waves thereby to form said directive beam of electromagnetic energy; means for varying said a dimension of said first waveguide over its length without changing said b dimension thereby to vary the phase of energy at each of said energy coupling means and consequently to vary the angle of said directive beam in a first of said orthogonal coordinates; and means for varying the frequency of said radio frequency waves thereby to vary the phase of energy along the lengths of said second waveguide sections and consequently to vary the angle of said directive beam in a second of said orthogonal coordinates substantially independently of the variation of the angle of said directive beam in said first orthogonal coordinate.

3. The invention set forth in claim 2 further defined in that said energy coupling means distributed along the length of said first waveguide sections comprise a series of coaxial probes arranged to form a corresponding series of coaxial transmission line links between said first waveguide section and said second waveguide sections.

4. The invention set forth in claim 2 in which said first waveguide section has one wall movable to vary said a dimension over the length of said first waveguide and further defined in that said means for varying said a dimension of said first waveguide section includes rotary motion mechanical drive means, means for converting said rotary motion to reciprocating motion of substantially simple harmonic type, and means for coupling said reciprocating motion to said movable wall.

5. The invention set forth in claim 2 further defined in that the forming of said second waveguide sections is such that said second waveguide sections are serpentine shaped in a plane normal to said plane of said array and have a plurality of bends of substantially 180° each joined by intervening substantially straight sections, said bends thereby generating a plurality of elbows tangent to said plane of said array, and said radiating elements are inserted into said elbows substantially along the line of tangency of said elbows with said plane of said array.

6. The invention set forth in claim 2 further defined in that the forming of said second waveguide sections is such that said second waveguide sections are serpentine shaped in a plane normal to said plane of said array and have a plurality of bends greater than 90° but less than 180° each joined by intervening substantially straight sections, said bends thereby generating a plurality of elbows tangent to said plane of said array, and said radiating elements are inserted into said elbows substantially along the line of tangency of said elbows with said plane of said array.

7. The invention set forth in claim 2 further defined in that the forming of said second waveguide sections is such that said second waveguide sections are serpentine shaped in a plane normal to said plane of said array and have a plurality of bends greater than 180° each joined by intervening substantially straight sections, said bends thereby generating a plurality of elbows tangent to said plane of said array, and said radiating elements are inserted into said elbows substantially along the line of tangency of said elbows with said plane of said array.

8. A directive antenna and scanning system including an array of radiating elements arranged in rows and columns for producing a beam of electromagnetic waves narrow in each of two polar space coordinates, and wherein scanning in a first of said coordinates is accomplished relatively slowly and relatively rapidly in the second of said coordinates comprising the combination of: a plurality of electrically separate transmission lines, one for each of said columns of elements arranged to feed all of said elements of the corresponding column, each such element from a predetermined position along the corresponding transmission line so as to provide an angle of radiation in said second coordinate which is a function of excitation frequency; phase distribution means comprising a rectangular cross-section waveguide, said transmission lines being fed discretely from successive predetermined points along the length of said waveguide thereby to effect excitation of said columns in corresponding predetermined successively offset phase relationship; transmitter means for providing energy at said excitation frequency to said phase distribution means thereby to provide radio frequency waves to form said beam; means for varying one of the cross-sectional dimensions of said waveguide of said phase distribution means, thereby to modify said offset phase relationships among said columns and consequently to cause said beam to assume a

corresponding new angular position in said first coordinate, without substantially affecting the angular position of said beam in said second coordinate; and means for varying the frequency of said excitation supplied to said phase distribution means by said transmitter means, thereby to vary the angular position of said beam in said second coordinate.

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RODNEY D. BENNETT, Jr., *Primary Examiner.*

D. C. KAUFMAN, *Assistant Examiner.*

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