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A Novel Implementation Technique of Conical Scan Radar Using A Programmable Phased Array

Q. Md. Alfred · T. Chakravarty · G. Singh · S. K. Sanyal

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Abstract In radar, planar phased array antenna plays vital role in electronic scanning in the azimuth and elevation direction to the horizon. In most operations using planar phased array both the coordinates of azimuth and elevation, are steered electronically. In this paper a conceptual schematic of a phased array antenna with programmable time delay units has been presented. It is shown that by suitably exploiting the time delay matrix one can have electronic beam rotation around the target axis as required in conical scan. Thus both the elevation and azimuth motors in conical scan system are replaced by electronic scanning. Heuristically, we have selected eight consecutive points for beam rotation in a polygon shape and can also be extended almost circular shape by increasing number of array elements and phase shifter (delays) in the delay matrix. The array requires dual control of phase gradient and individual phase values. The whole array is controlled by micro-controller. This presents exciting possibilities in radar operation.

Keywords Phased array antenna · Azimuth · Elevation · Delay matrix · Conical scan · Digital phase shifter · Bit multiplier · Microcontroller

Q. Md. Alfred
Department of Electronics and Communication Engineering, University Institute of Technology, Burdwan University, Burdwan 713 104, India

T. Chakravarty · G. Singh (✉)
Department of Electronics and Communication Engineering,
Jaypee University of Information Technology, Solan 173 215, India
e-mail: drghanshyam.singh@yahoo.com

S. K. Sanyal
Department of Electronics and Telecommunication Engineering, Jadavpur University,
Kolkata 700 032, India

1 Introduction

In a conical scan tracking system of radar, a squinted beam rotates around the target in elevation as well as azimuth direction. When conical scan is used for tracking a target, the target is never touched by the peak of the beam. The peak of the beam circularly rotates about the target. The motion of beam axis forms a cone in space. The axis of the radar lobe is made to sweep out a cone in space, the apex of this cone is at the radar transmitter antenna or reflector. Typically, the conical scan rate is in the range of 25 to 80 Hz. The other parameter of interest in this case is the beam axis squint angle. In typical conical scan radar, a single parabolic dish is used. There are two servo motors used, one for elevation and the other one for azimuth [1–3]. We use a conical scan beam for target tracking. If the target is on the scan axis, the strength of the reflected signals remains constant, but if the target is slightly off the axis, the amplitude of the reflected signals will change at the scan rate.

In this paper, a conceptual variation to implementation of a conical scan antenna system has been presented. The single parabolic dish is replaced by an array of antennas with programmable time delay units attached to each antenna to be used for progressive phase shift between elements. The elevation motor based scanning is replaced by electronic scanning that is beam steering. The use of time-delay units brings into focus the possibility of broad band arrays. Also application of adaptive techniques with a micro-controller control leads to a possibility of simultaneous multiple lobing which is the current area of research. The objective in this paper is to use the micro-controller based control of delay line matrix for generation of antenna beam which will scan the horizon conically. The concept is demonstrated using six by six planar array and three layers of delay matrix for linear as well as planar section. A Generic delay matrix for systematic delay gradient (+/−) like T, 2T, 3T, 4T *etc*. can be achieved through proper switching algorithm which is programmable by microcontroller or PC [4]. Rapid switching can be obtained by PIN switches. Frequency band of operation can be increased by using such constant time matrix.

Utilization of phased array antenna for conical scan, using variable time delay units is a concept that combines existing knowledge in a new application [5–8]. In a recent work, authors have reported the concept of programmable time-delay units in clutter attenuation as well as elimination of blind speed [5]. With the advent of microcontroller based control systems in large scale in various applications, a radar system that displays reasonable performance with simplification in hardware leads to an exciting new possibility in technology. In [5], authors have reported the method to eliminate blind speed. In the present proposal, authors attempt to utilize the fundamental schematic for conical scan radar which shows a significant improvement over existing methods of designing conical scan radar in terms of simplicity, bandwidth of operation and cost effectiveness.

2 Antenna schematic

The six by six planar antenna schematic with time delay units is shown in Fig. 1. There are six antenna arrays with each array connected to delay units in the layers named as D, E, F. Each array has six elements connected to delay matrix named as A, B and C. Thus, for RF to traverse the complete path, one switches each from A, B, and C is to be closed [6]. Similar is the case for E, F and D. It is necessary to outline that in the present schematic when one particular switch say D_0 is ON thereby inserting 5T delay in the left-most array, the corresponding switches with other arrays are also ON thereby inserting 4T, 3T, 2T, T and 0T. By judicious choice of switch selection, progressive phase gradient in ±X and ±Y

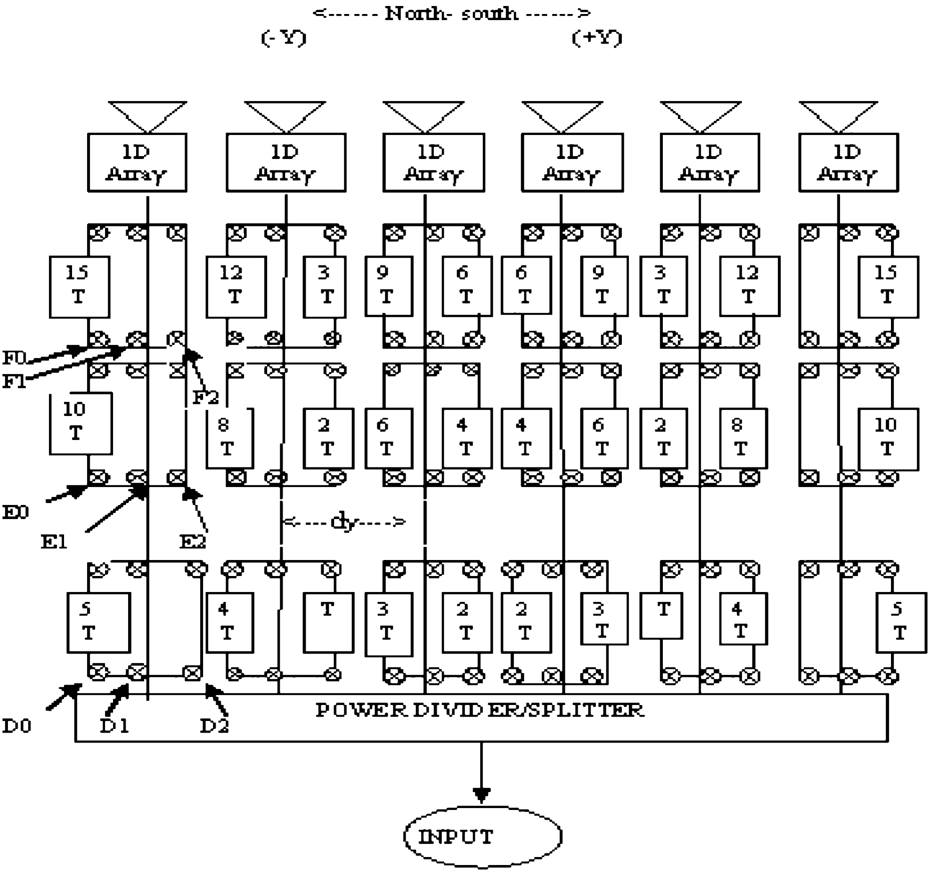


Fig. 1 A planar array with time delay units.

direction can be introduced. Table 1 lists the switch position ("1' for ON) and corresponding progressive delay. From Table 1 it is seen that the beam can be tilted in both East-West and North-South directions using independent control of A, B, C, D, E, F switches.

Table 1 Switching pattern for 6×6 planar array.

A_0 / D_0	A_1 / D_1	A_2 / D_2	B_0 / E_0	B_1 / E_1	B_2 / E_2	C_0/ F_0	C_1 / F_1	C_2 / F_2	Progressive Delay (Direction)
0	1	0	0	1	0	0	0	1	+T in *East/South*
0	0	1	0	1	0	0	1	0	+2T in *East/South*
0	1	0	0	0	1	0	0	1	+3T in *East/South*
0	0	1	1	0	0	0	0	1	+4T in *East/South*
0	0	1	0	1	0	0	0	1	+5T in *East/South*
0	0	1	0	0	1	0	0	1	+6T in *East/South*

T=Unit delay

For a planar phased array, the following relations hold true [9]:

$$\beta_x = -kd_x \sin\vartheta_0 \cos\phi_0 \tag{1}$$

and

$$\beta_y = -kd_y \sin\vartheta_0 \sin\phi_0 \tag{2}$$

where θ_0 is the elevation angle measured from zenith and ϕ_0 is the azimuth angle measured from +X (East) direction in anti-clockwise rotation. Here β_x and β_y are progressive phase shift, d_x and d_y are inter-element spacing in X & Y direction respectively. For this case, d_x = d_y = d. Solving simultaneously

$$\tan\phi_0 = \frac{\beta_x}{\beta_y} \tag{3}$$

$$\sin^2\vartheta_0 = (\frac{\beta_x}{kd})^2 + (\frac{\beta_y}{kd})^2 \tag{4}$$

We can set some representative parameters as: dx = dy=0.78λ and T=π/4 radian and switch controls as: A_0=0, A_1=1, A_2=0, B_0=0, B_1=1, B_2=0 and C_0=0, C_1=0, C_2=1 for linear array to obtain +T in -X direction (or East) and D_0=0, D_1=1, D_2=0, E_0=0, E_1=0,E_2=1 and F_0=0, F_1=0 ,F_2=1 for 3T in -Y direction (or South) for planar array. Substituting the values of β_x = -π/4 and β_y = -3π/4 in expressions (3) and (4) we get θ_0=30.449 from zenith and φ_0= 71.565. (towards North) So the resultant beam is tilted at 30.449^0 from broadside direction at 71.565^0 on East-North direction.

3 Schematic of conical scanning

In the preceding section we have demonstrated the possibility of two-dimensional scanning over the entire hemisphere. We can now incorporate conical scanning by exploiting the same delay matrix in Fig. 1. Here we propose to use 8 bit digital phase shifter (resolution of 1.4 deg) instead of delay line because, for conical scanning both the azimuth and elevation angle should be changed simultaneously so that the beam point rotates concentric to a point. In this paper we have chosen some discrete points so that it gives the locus a polygon shape and can be extended to circular shape by choosing larger delay matrix and higher resolution of digital phase shifter. In Table 2 the bit control of digital phase shifter is presented.

Switching on the respective bit pattern, introduces the required phase shift β_x and β_y which rotates the beam in both elevation and azimuth. The Table 3 shows the approximate relational values of elevation and azimuth for the beam to scan conically and the corresponding delay gradient in X and y direction. For this case the inter-element spacing is chosen to be λ/2. From the Table 3, it can be deciphered that there must be a dual control of

Table 2 Bit pattern and phase shift of a 8 bit digital phase shifter.

Bits	1	2	3	4	5	6	7	8
Phase shift (in degrees)	1.4	2.8	5.6	11.2	22.4	44.8	89.6	179.2

Table 3 Switching Pattern for 6×6 planar conical scanning array.

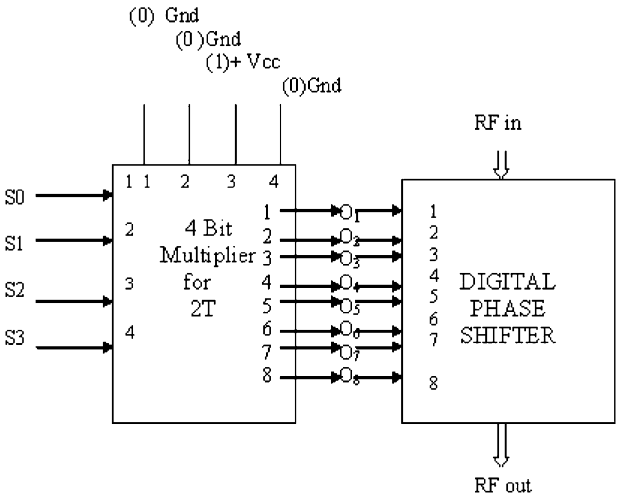
Elevation angle(θ) (in deg)	Azimuth angle(φ) (in deg)	Phase diff. X dir(βx)	Phase diff. y dir(βy)	Calculated Variable T (deg/rad)	Approximate Phase shifter delay w.r.t T(in deg)	Bit switching
18	68	2T	5T	31.4 (pi/18)	30.8	5+3+2
25	71.5	T	3T	80.8 (pi/7)	81.2	6+5+4+2
29	75.9	T	4T	66.5 (pi/8.5)	67.2	6+5
25	78.7	T	5T	47.1 (pi/12)	47.6	6+2
18	80.8	T	6T	29.7 (pi/19)	29.4	5+3+1
12	78.7	T	5T	22.6 (pi/25)	22.4	5
7	75.9	T	4T	16.1 (pi/35)	15.4	4+2+1
12	71.7	T	3T	37.7 (pi/15)	37.8	5+4+2+1
18	68	2T	5T	31.4 (pi/18)	30.8	5+3+2+1

Unit Delay T (time delay) dx = dy = λ/2

delay (phase) matrix as well as unit phase delay for the conical scanning of planar array at each set of elevation and azimuth direction. The elevation and azimuth angle can be obtained from the expression of (3) and (4). This dual control is obtained using a micro-controller.

Figure 2 shows the control mechanism of the digital phase shifter using a micro-controller. In Fig. 2, S0, S1, S2, S3, S4 are inputs from Microcontroller for variable Unit delay T. Output of the multiplier at each delay is input to the digital phase shifter. As per our discussed algorithm, microcontroller or computer is programmed to activate the delay matrix as well as variable delay with suitable bit pattern so that the resultant beam in planar array scans conically. Fig. 3 represents the graphical display of the locus of the conical scan undertaken by the beam as given in Table 3. Since the aperture area is small the 3dB beam-width (θ_B) for the array is high, of the order of 52^0. For the present case the squint angle (θ_q) is 10^0. In Fig. 4.7 of [1], the slope of angle error signal at crossover is presented. Using the graph, we see that for θ_q / θ_B=0.2, the value of "θ_B X slope of error signal voltage at cross over" = 2 and the beam crossover is 0.5dB.

Fig. 2 Microcontroller based control of digital phase shifter.



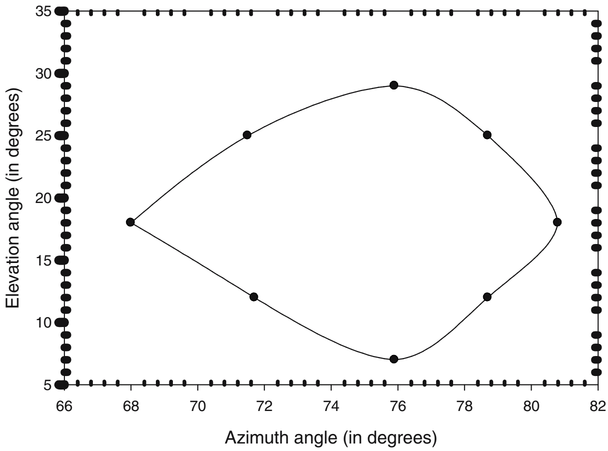


Fig. 3 Locus of azimuth versus elevation angle for conical scan.

4 Experimental feasibility

The proposed delay line matrix has inherent advantages that delay line phase shifter with constant time delay operate over large bandwidth. For example, 6 bit phase shifter available as MMIC chip from M/S Norda Microwave [10], operate from X to K band. One can form a delay line of say 15T using fifteen numbers of IC's in cascade. The control lines of all the phase shifters introduced in the delay matrix are connected to the same microcontroller outputs. Microcontroller bit setting selects the requisite "T" value in each phase shifter and the progressive phase delay (e.g. 2T) is selected by the RF switch controls. Therefore delay unit has three control bits for switch control and four eight bits for phase shifting control.

5 Conclusions

In this paper, a conceptual schematic of an electronic scanning in conical scan radar has presented. Both the elevation and azimuth angle motors used with a parabolic antenna is replaced by a planar array with programmable digital phase shifter. Electronic scanning mechanism is used to rotate the beam around target axis. The antenna array is proposed to rotate in azimuth plane electronically in small discrete steps. In the present scheme, only 36 elements have been used. Due to constraint in inter-element spacing the beam-width is large, so, optimum beam crossover is not achieved. However, using a larger array, it is possible to reduce the beam-width, have a circular locus of beam rotation and achieve optimum beam cross over. The proposed array operates with control signals obtained from micro-controller. The micro-controller can be used for beam rotation in elevation as well as azimuth. The proposed schematic is a very useful tool as track vehicle scan radar using a simple low cost and wideband delay matrix technique a target can be located and tracked electronically.

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