Int J Wireless Inf Networks (2009) 16:59–67
DOI 10.1007/s10776-009-0090-4

A Programmable Phased Array with Time-Delay Units and its Applications

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

Published online: 26 March 2009

Abstract In this paper, a phased array antenna schematic using true time delays is proposed and suitable time-delays are inserted by switching ON/OFF the RF switches. Using this concept, one can generate SUM pattern, DIFFERENCE pattern, as well as a combination of these two. It is shown that SUM-DIFFERENCE pattern has interesting applications in radar, namely, calibration of beam pointing accuracy and blind speed elimination in a delay line cancellation method. The proposed method can also be formatted to requirements of conical scan as well as shaped beam generation. The proposed method is validated using existing knowledge.

Keywords Phased array time-delay · Conical scan · Microcontroller · Phase shifter · Shaped beam

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

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

T. Chakravarty
Tata Consultancy Services, Abhilash Software Development Centre EPIP Industrial Area, Whitefield, Bangalore 560 066, India

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

1 Introduction

Phased array antennas are widely used in the radar systems and also find its worth in the field of satellite and mobile communication systems. Conventionally, a phased array antenna relies upon the phase-shifters for electronic beam steering and for other capacities [1]. But the efficiency is limited for having phase-shifters [2]. They have a limited range of the frequency of operation as they primarily depend upon phase-shifter characteristics. They require a complex control circuitry for switching the phase-shifters which also overheads on the cost of designing a phased array system.

In this communication, a different approach on beam steering and scanning is realized. Unlike the conventional use of phase-shifters in beam-formation, focus is given here on time-delay units (delay-lines). The time-delay unit inserts progressive phase gradient between antenna elements, hence by designing a programmable switching matrix beam steering and beam synthesis is possible which is explained in the next section. This offers real advantage in designing a wideband phased array system. This method of beam steering (beam formation) is exploited in several areas of application that is SUM and DIFFERENCE pattern generation, calibration, blind speed elimination, conical scanning, etc. The SUM and DIFFERENCE patterns may be generated simultaneously for the calibration of large phased array antennas. A hybrid matrix using time-delays and phase shifters may be applied for conical scanning. Again, the technique is employed for blind speed elimination in radar instead of traditional delay-line approach.

Finally, a simple method for shaped pattern (beam) generation has been conceptualized. Conventionally, the shaped patterns are generated by perturbing the radiating elements with appropriate phase and amplitude weights, which are obtained from different procedures [3–6]. But in this proposition, the whole array is subdivided into few subarrays and the patterns form each subarrays are approximately added to generate desired shaped pattern. To implement this, individual element in each subarray is loaded with suitable phase tapering (delay line) which place the beams (from subarrays) in a desired direction. When any subarray beam overlaps with an adjacent beam, a shaped envelope is obtained otherwise it produces a null in the final pattern. Here, the generation of cosecant and sector beam is represented as the shaped pattern.

2 Antenna Schematic and Generation of Sum Pattern

A 6 × 6 planar array with time delay units is depicted in Fig. 1. In this schematic, there are six (6) linear arrays and each array is connected to a set of time delays (in terms of unit delay T) into the levels designated as *D*, *E*, and *F*. Similarly, each array also consists of six (6) radiating elements connected to the same 3-level delay matrix (not shown), may be assumed as *A*, *B*, and *C* [7]. Thus, for RF signal to traverse the complete path, only one DP3T PIN switch in each level (*D*, *E*, and *F*) should be 'ON' while keeping others 'OFF'. Similar is the case for A, B, and C. It is necessary to outline that when one particular switch in level-D, say D_0 is 'ON'(means D1, D2 'OFF'), inserts 5*T* delay in the left-most array, the corresponding switches with other arrays are also ON thereby inserting 4*T*, 3*T*, 2*T*, *T* and 0*T*. Therefore, programmable selection of PIN switches introduce progressive phase gradient in ±X (for linear array) and ±Y direction (for planar array). Here, +X indicates the eastward inclination of main beam away from boresight (broadside) direction (90°) whereas −X indicates the opposite direction (westward from boresight). Similarly, +Y/−Y directions denotes north/south inclination form zenith (broadside), which is perpendicular to ±X directions.

Table 1 represents some switching combinations ("1" for ON, '0'for OFF) for SUM pattern in respect to the RF switches and the resulting delay gradients. It is clear from Table 1 that the beam can be electronically steered toward East–West and North–South directions using independent control of *A*, *B*, *C*, *D*, *E*, *F* switches. Here, an additional layer is inserted in the planar array (Fig. 1) for the selection of either SUM or DIFFRENCE pattern. For SUM pattern $L1 = R0 = 1$ and for DIFFERENCE pattern, either $L0 = R0 = 1$ (for –X direction) or $L1 = R1 = 1$ (for +*X* direction). This is done because, DIFFERENCE pattern requires 180° additional phase difference between halves of the array elements. Therefore, the equivalent delay is 6*T* considering unit delay $T = \pi/6$. For a planar phased array, the following relations hold true [8]:

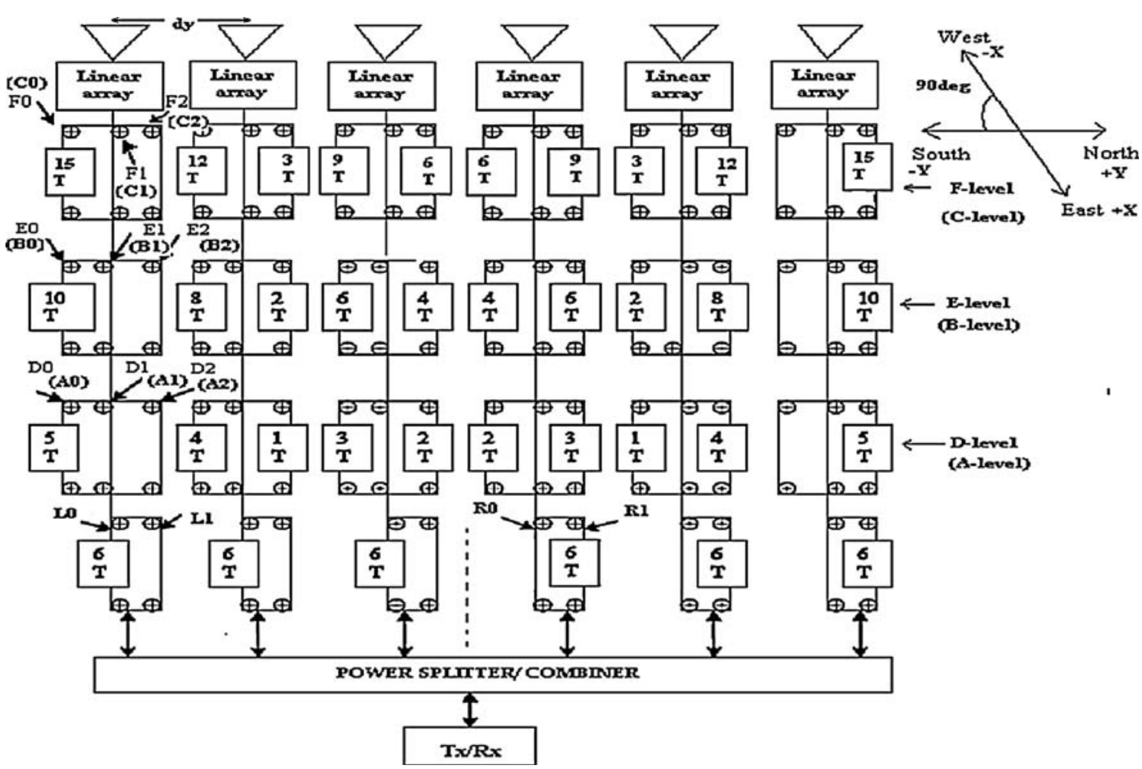


Fig. 1 Schematic of planar array with programmable switched time-delay units

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	0	1	0	1	0	0	1	0	+T
0	1	0	0	0	1	0	1	0	+2T (East–South)
0	1	0	0	1	0	0	0	1	+3T (East–South)
0	0	1	0	1	0	0	0	1	+4T (East–South)
0	1	0	0	0	1	0	0	1	+5T (East–South)
0	0	1	0	0	1	0	0	1	+6T (East–South)

T = Unit delay

$$\beta_x = -kd_x \sin\theta_0 \cos\phi_0 \tag{1}$$

and

$$\beta_y = -kd_y \sin\theta_0 \sin\phi_0 \tag{2}$$

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 and Y direction, respectively. For this case, $d_x = d_y = d$. Solving simultaneously

$$\tan\phi_0 = \frac{\beta_y}{\beta x} \tag{3}$$

$$\sin^2\theta_0 = \left(\frac{\beta_x}{kdx}\right)^2 + \left(\frac{\beta_y}{kdy}\right)^2. \tag{4}$$

Here, one representative case is considered follows: $d_x = d_y = 0.5\lambda$ and $T = \pi/6$ rad 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 $+3T$ (β_x) in $+X$ direction (or east) and $D_0 = 0$, $D1 = 1$, $D_2 = 0$, $E_0 = 0$, $E_1 = 0$, $E_2 = 1$ and $F_0 = 0$, $F_1 = 0$, $F_2 = 1$ for $+5T$ (β_x) in +Y direction (or South) for planar array. Substituting the values of $\beta_x = +3\pi/6$ and $\beta_y = +5\pi/6$ in expressions (3) and (4) we get elevation angle, $\theta_0 = 85.65°$ and azimuth angle, $\phi_0 = 65.55°$.

3 Generation of Difference Pattern

In this unique scheme, a DIFFERENCE pattern is generated in linear as well as planar domain. The centre null position scans on either side of zenith. Consider the control switch position for linear case as follows.

A_0	A_1	A_2	B_0	B_1	B_2	C_0	C_1	C_2	L0	L1	R0	R1	Progressive delay (direction)
0	1	0	0	0	1	0	1	0	0	1	0	1	+2T

(Eastward)

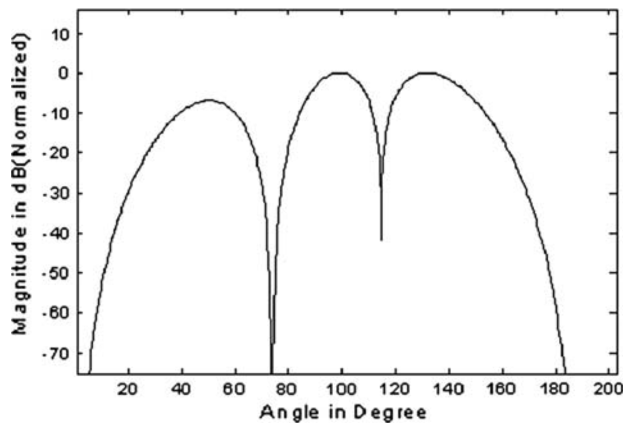


Fig. 2 DIFFERENCE pattern at delay gradient +2T ($T = \pi/6$) near 20° (109.5°) westward direction

The progressive time delay units in $+X$ direction are 0, $2T$, $4T$, $12T$, $14T$, $16T$. This results in a DIFFERENCE pattern with null position at 109.471° Eastward or 19.47° from boresight direction. Figure 2 shows this DIFFERENCE pattern. Similar to this, by changing the control bits $A2$ and $B2$ to "1" result in a DIFFERENCE pattern at boresight direction. The delay units for null at the zenith (boresight) are 0, 0, 0, $6T$, $6T$, $6T$.

4 Calibration Techniques

The true-time delays along with RF switches incorporate delay errors in the beam steering. Therefore, calibration of large phased arrays is required to off-set the beam-pointing errors. In an interesting approach to far-field measurements and calibration of very large sized array antenna, radio source has been used [9, 10]. The noise temperature of the radio source Virgo-A (3C 274) was measured in the receive mode during its transit over the radar. The source under consideration should have appropriate right ascension and declination to be able to pass through the antenna array beam. The atmospheric radar had 256 Yagi elements operating at 53 MHz. In this paper, a conceptual variation to similar far-field measurements is presented. In this proposed method suitable selection of delay unit result in

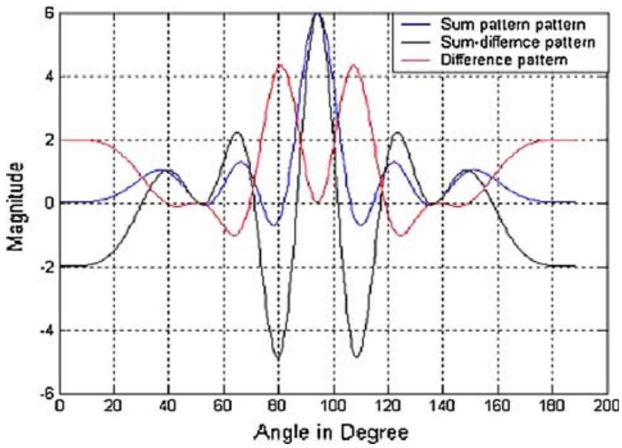


Fig. 3 SUM, DIFFERENCE, and SUM-DIFFERENCE patterns

either SUM pattern or DIFFERENCE pattern. The SUM-DIFFERENCE pattern can be utilized for measurement of primary accuracy as shown in Fig. 3. This is demonstrated in the following sections.

For measurement of beam pointing accuracy of less than 0.5°, a broad beam SUM pattern will not suffice. It is necessary to have a sharply pointed beam looking up at the target. This can be generated using SUM-DIFFERENCE pattern. Toggling the control bits in synchronization to a 1 KHz clock, the alternate SUM pattern and DIFFERENCE pattern are obtained and the difference in amplitude of the detected signal is taken. It is evident that for the resultant narrow beam, the measurement of beam pointing accuracy is much more meaningful.

5 Applications

In this section, few potential applications of the proposed antenna configuration such as delay line cancellation, conical scan, and shaped beam generation is discussed.

5.1 Delay Line Cancellations

Consider an array of an even number of elements 2 M is positioned in the X–Y plane with Z axis being the direction of propagation. The inter-element spacing is d and M elements are placed on each side of origin. Assuming that the amplitude excitation is symmetrical about the origin, the normalized array factor for SUM pattern (for non-uniform amplitude and same phase in each element) is given as:

$$(\mathrm{AFS})_{2M} = \frac{1}{M}\sum_{n=1}^{M} a_n \cos\left[\frac{(2n-1)}{2} kd \cos\left(\frac{\pi}{2}-\theta\right)\right] \quad (5)$$

where, θ is measured from broadside direction. In the DIFFERENCE pattern, one half of the array has phase value of zero and the other half has phase value of π. The resultant array factor for the DIFFERENCE pattern is:

$$(\mathrm{AFD})_{2M} = \frac{1}{M}\sum_{n=1}^{M} a_n \sin\left[\frac{(2n-1)}{2} kd \cos\left(\frac{\pi}{2}-\theta\right)\right]. \quad (6)$$

We obtain the SUM-DIFFERENCE pattern from subtracting Eq. 6 from 5. For the SUM-DIFFERENCE pattern the beamwidth is narrow. It is also generates negative amplitude over a large range of elevation angles. By controlling the progressive phase difference between the elements, all the three beams can be squinted to give a maximum radiation in a given direction.

It is shown in [11] that the response of a single-delay line canceller goes to zero whenever the moving targets have the Doppler frequencies at the pulse repetition frequency (PRF) and its integer multiples. This happens because the amplitude of the signals received from pulse to pulse is assumed to remain the same. However, in the present proposition a single delay-line canceller with unequal amplitudes is considered. To satisfy this criterion, different beam patterns are utilized from pulse to pulse. The received signal (voltage) in the SUM beam with delay is:

$$V_1 = K\sin\{\omega_d(t-T_p)-\phi_0\} \quad (7)$$

and the received signal in the DIFFERENCE beam is:

$$V2 = K'\sin\{\omega_d t-\phi_0\}. \quad (8)$$

Here $\phi_0 = 4\pi R_0/\lambda$, where R_0 is range between target and radar, T_p is pulse repetition period of radar transmitter and ω_d is the angular Doppler frequency. Subtracting (SUM-DIFFERENCE) Eq. 8 from Eq. 7 gives:

$$\begin{aligned} V_1 - V_2 = {} & K\cos\phi_0\{\sin\omega_d t[\cos\omega_d T_p - K'/K] \\ & - \sin\omega_d T_p \cos\omega_d t\} \\ & - K\sin\phi_0\{\cos\omega_d t[\cos\omega_d T_p - K'/K] \\ & - \sin\omega_d T_p \sin\omega_d t\}. \end{aligned}$$

If the amplitude components $\cos\omega_d T_p - K'/K$ and $\sin\omega_d T_p$ both are zero, above result will provide blind speeds at the received Doppler frequencies of $\pm\, nf_p$ (where $f_p = 1/T_p$). But here, due to their unequal amplitudes in the SUM and DIFFERENCE pattern (or if $K' < K$ is chosen) blind speeds can be eliminated.

5.2 Schematic of Conical Scanning

In the preceding sections, the possibility of 2-D electronic scanning over the entire hemisphere has been demonstrated. Now, the same delay matrix in Fig. 1 has been modified for conical scanning. Table 2 specifies the bit weights of the digital phase-shifter, where bit-1 represents LSB, whereas bit-8 represents MSB. Here, instead of the fixed time-delay units (in terms of unit delay T), 8-bit

Table 2 The bit weights and corresponding phase shifts

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

digital phase-shifters (resolution of 1.4°) are employed for the generation of unit phase-shift T. So, the unit phase-shift T can be varied accordingly. For conical scanning, both the azimuth and elevation angle to be changed simultaneously (rapidly), so that the beam-point rotates concentrically around to a target. To establish this idea for a single case, a representative set of discrete locations in the horizon is considered in Table 3 (col-1, col-2), the locus of which forms a polygon shape. This can be extended to near-conical shape by choosing larger delay matrix and higher resolution of digital phase shifter.

By loading (from microcontroller) appropriate bit-pattern in the inputs of digital phase-shifters, unit phase-shift T can be generated, which in combine with the delay network provide the required phase shifts β_x and β_y, which directs the beams in pre-fixed locations in terms of elevation and azimuth angles. Col-3 and col-4 of Table 3 elaborates phase gradients in X and Y directions (in terms unit phase-shifts T) for respective elevation and azimuth angles. In Col-5, unit phase-shifts has been calculated and they have been approximated in terms of the phase-shifts may be available from the digital phase-shifter. To avoid the loss of generality, inter-element spacing $\lambda/2$ is taken.

From Table 3, it can be deciphered that a dual control of the delay (phase) matrix as well as unit phase-shift must be ensured so that each set of elevation and azimuth angles are obtained. The elevation and azimuth angle can be obtained from the expression of (3) and (4). This dual control is obtained using a micro-controller as shown in Fig. 4. Here, the 4 bit multiplier is employed for generating multiples of

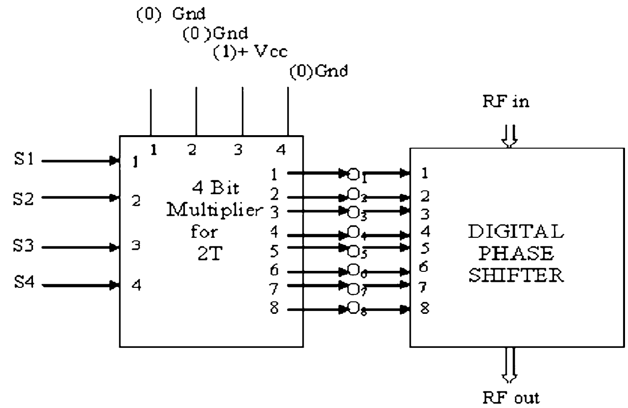


Fig. 4 Microcontroller based control of digital phase shifter

unit phase shifts (e.g. $2T$, $3T$, $4T$, etc.), whereas S1, S2, S3 and S4 are the inputs from the microcontroller to generate unit phase shift T as required.

Figure 5 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 3 dB beam-width (θ_B) for the array is high, of the order of 52°. For the present case the squint angle (θ_q) is 10°. In Fig. 4.7 of [11], the slope of angle error signal at crossover is presented. Using the graph, we see that for $\theta_q/\theta_B = 0.2$, the value of "θ_B X slope of error signal voltage at cross over" 2 and the beam crossover is 0.5 dB.

5.3 Generation of Shaped Beam

In the radars, pencil beams are mainly employed for tracking and searching purposes, whereas shaped beams has a special areas of application such as airport landing system, mobile base station, satellite communication, etc. The antenna patterns has its special shape in airport beacon system, where they have to maintain almost constant shape

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

Elevation angle (θ) (in deg)	Azimuth angle (ϕ) (in deg)	Phase difference X dir (β_x) (from delay matrix)	Phase difference Y dir (β_y) (from delay matrix)	Calculated unit phase-shift T (deg/rad)	Equivalent phase shift T (in deg) (from phase shifters)	Bit combination
18	68	2T	5T	31.4 (π/18)	30.8	5 + 3 + 2
25	71.5	T	3T	80.8 (π/7)	81.2	6 + 5 + 4 + 2
29	75.9	T	4T	66.5 (π/8.5)	67.2	6 + 5
25	78.7	T	5T	47.1 (π/12)	47.6	6 + 2
18	80.8	T	6T	29.7 (π/19)	29.4	5 + 3 + 1
12	78.7	T	5T	22.6 (π/25)	22.4	5
7	75.9	T	4T	16.1 (π/35)	15.4	4 + 2 + 1
12	71.7	T	3T	37.7 (π/15)	37.8	5 + 4 + 2 + 1
18	68	2T	5T	31.4 (π/18)	30.8	5 + 3 + 2

Unit delay T (time delay) $dx = dy = \lambda/2$

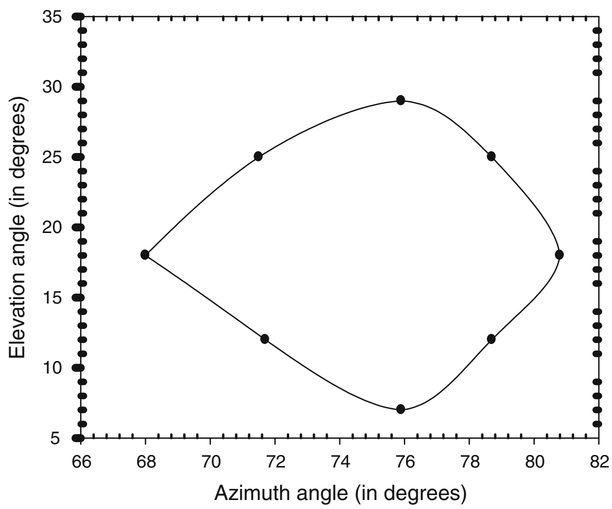


Fig. 5 Beam locus in conical scan radar

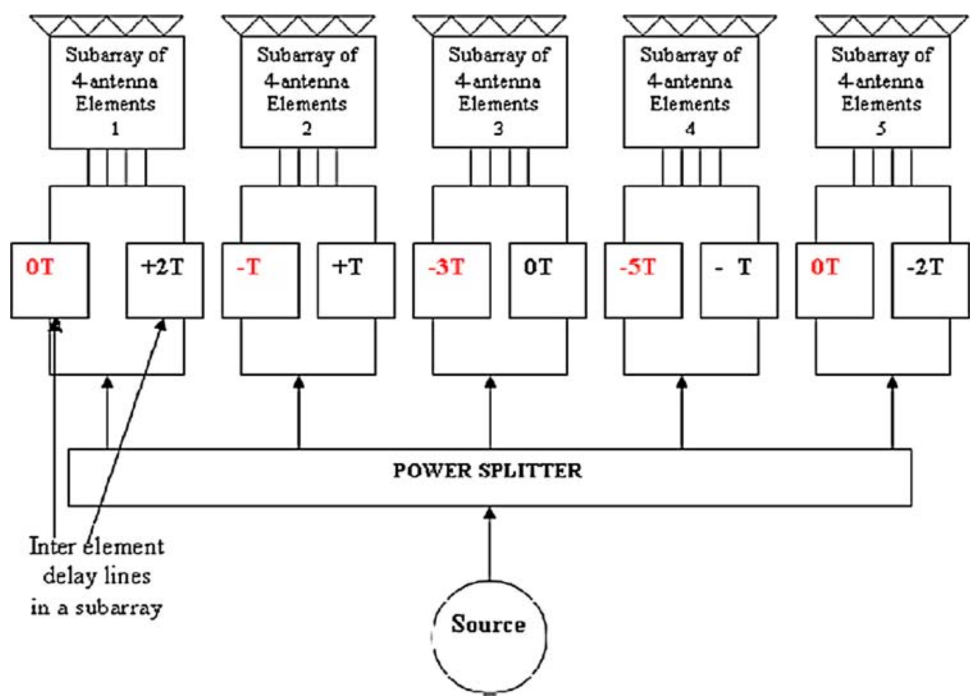
(power)throughout the range from zenith to horizon without having any null, but require a fall (null) sharply at the zenith. Such asymmetrical patterns are known by their decaying envelopes, like cosecant, cosecant squared, etc. Another shaped beam is sector pattern, which is also widely used in mobile base-stations and satellite earth-stations for illuminating an angular region. The synthesis of shaped beam pattern was earlier developed by Woodward and Lawson [12] and then mathematically précised by Elliot and Stern [13]. But both the methods were based on amplitude and phase control method. The methods of generating shaped patterns with complex weights are limited by several disadvantages that is inefficient utilization of transmitter power, hardware complexities, device saturation etc. In view of this, phase-only techniques are most realizable, where only phase-weights are selectively applied to radiating elements. Here, a practical approach based on the notion of phase-only technique is introduced as follows.

5.3.1 Design and Analysis

As mentioned previously, shaped beams are generated by exciting antenna element with varying phase and amplitude weights. But here, the constituents beams from subarrays (here five subarrays) are spatially added to generate shaped patterns. For each subarray, a delay gradient is to be generated to locate its beam in a prefixed direction. Schematic in Fig. 1 is referred for generating different delay gradient. When one subarray pattern overlaps the adjacent subarray pattern, the null can not be formed but an envelope of antenna pattern is obtained. Here, generation of two representative shaped beams, cosecant and sector beam is highlighted.

In this proposition, a 20-element linear (one dimensional) array is first considered and then they are grouped into five individual subarrays, is shown in Fig. 1. Figure 6 depicts that two set of delay gradient is selected, where the left one used for synthesis of cosecant type pattern and right one for sector pattern. Each subarray consist of 4 antenna elements, where they are separated uniformly by $d = 0.4\lambda$. Let, in subarray-1, each antenna element is connected with two parallel delay paths, they may be $0T$, $0T$, $0T$, $0T$, which offers the gradient of $0T$, whereas for

Fig. 6 Delay matrix of 20-element linear array for shaped beam generation



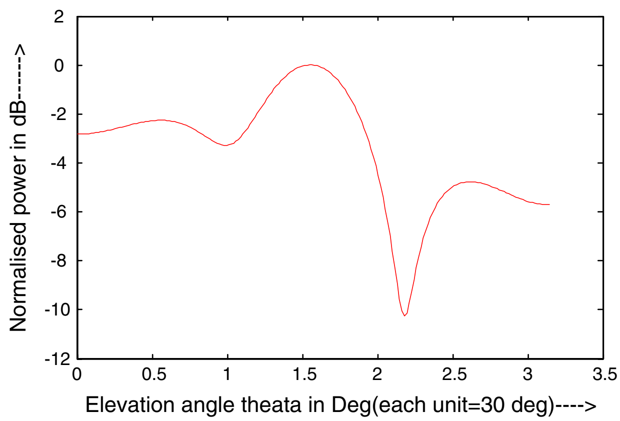


Fig. 7 Simulated result of shaped beam (cosecant) pattern

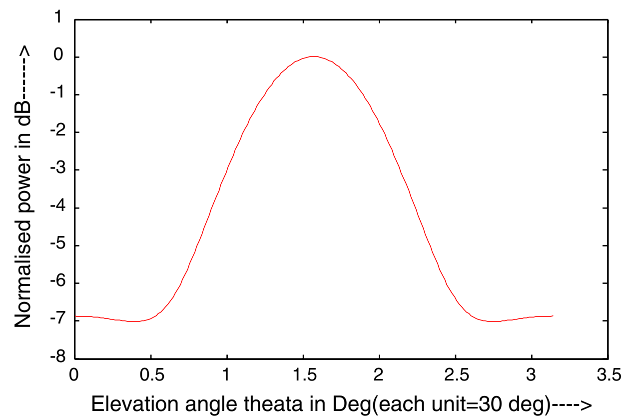


Fig. 8 Simulated result of shaped beam (sector) pattern

$+2T$, the delays may be $0T$, $2T$, $4T$, $6T$). Similarly, in the subarray -2, they connected with two types of delay gradients are $-$T (delays are $3T$, $2T$, T, $0T$) and $+T$ and same is true for subarray-3 subarray-4 and subarray-5. For acceptable result, the unit delay (T) is recommended for $\pi/8$. Hence, programmable switching is required for the selection of desired set of time delays, which will either generate sector pattern or cosecant pattern. Total eight pin switches (4 + 4) are to be required in this regard.

5.3.1.1 Case-1 Let consider the case, when gradients in the sub-arrays are $0T$, $-T$, $-3T$, $-5T$, $0T$, respectively. Subarray-5 is optimal to keep only with sector beam. Due to the phase gradient $0T$ in subarray-1, main beam will be directed in broadside direction (90°), which is normal to the aperture plane, this should be considered here as zenith. Similarly, $-T$ for subarray-2, $-3T$ for subarray-3, $-5T$ for subarray-4 and $0T$ subarray-5 generates beam maxima at 81, 62, 39, and 90°, respectively, which is obtained from the following expression [8].

$$AF(\theta) = \frac{\sin(N\psi/2)}{N\sin(\psi/2)} \tag{9}$$

where, $\psi = kd\cos\theta + \beta$. The resultant shaped pattern is obtained after interpolation of the constituents beams. Figure 7 shows the Matlab simulation result at $T = \pi/8$, where pattern is maximum at the zenith (90°) and almost constant along horizon but sharply falls after it.

The beam positions are tabulated as follows:

Subarray	Delay gradient (T)	Elevation angle (θ)
1	0	90°
2	$-\pi/8$	81° (9 from zenith)
3	$-3\pi/8$	62°
4	$-5\pi/8$	39°
5	0	90°

5.3.1.2 Case-2 Again, when the delay gradients in the subarrays are selected, respectively, as $+2T$, +T, $0T$, $-T$, $-2T$, then corresponding beam position are as follows.

Subarray	T	Elevation angle (θ)
1	$2\pi/8$	108°
2	$\pi/8$	98°
3	0	90°
4	$-\pi/8$	81°
5	$-2\pi/8$	71°

Therefore, the sector beam will be symmetrical with respect to the zenith (90°) and beam width will be of 40°. Simulation result by Matlab as shown in Fig. 8.

6 Control Mechanism of the Array

This schematic has an inherent advantage, because the RF switches are rapidly controlled by a micro-controller. The simultaneous control of switching matrix as well digital phase-shifter value has been introduced in Sect. 5.2. Here, the flow chart of the control mechanism is depicted Fig. 9. The micro-controller generates the switching pattern in terms of 'bits' at its output. These 'bits' are fed to a driver circuit which generates the driving voltage for the pin switches. The response time is limited by the switching time of the pin diodes.

7 Conclusions

In this paper, a conceptual schematic of the time-delay based programmable phased array antenna and its potential application are highlighted. The delay units are inserted in the RF path by switching ON respective PIN switches.

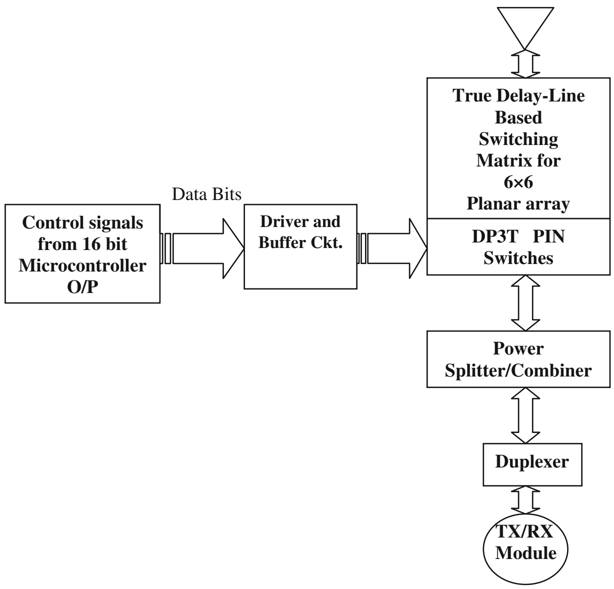


Fig. 9 Flow chart of the control mechanism of the programmable phased array

Apart from electronics steering of SUM pattern, this method can also be used to generate DIFFERENCE pattern which in turn can be steered. Therefore, it is possible to generate SUM-DIFFERENCE pattern which has narrower beam width. Using the SUM-DIFFERENCE pattern, one can calibrate the array as well as eliminate blind speed in a delay line cancellation method. Other applications of such schematic are also presented.

Acknowledgment Authors are sincerely thankful to the reviewer for critical comments and suggestions to improve the quality of the manuscript.

References

1. R. C. Hansen, *Microwave Scanning Antennas*, Vol. 1, Academic Press, New York, 1964.
2. R. J. Mallioux, *Phased Array Antenna Handbook*, Artech HouseMA, 2005.
3. W. L. Stutzman, Synthesis of shaped-beam radiation patterns using the iterative sampling method, *IEEE Transactions on Antennas Propagation*, Vol. 19, pp. 36–41, 1971. doi:10.1109/TAP.1971.1139892.
4. W.- C. Wu and Y. J. Wang, A study of beam pattern generation methods for antenna array system, *Journal of Science and Engineering Technology*, Vol. 1, No. 2, pp. 7–12, 2005.
5. A. Chakraborty, B. N. Das and G. S. Sanyal, Determination of phase functions for a desired one dimensional pattern, *IEEE Transactions on Antennas Propagation*, Vol. AP-29, pp. 502–506, 1981. doi:10.1109/TAP.1981.11426021.
6. R. S. Elliot, A new technique for shaped beam synthesis of equispaced Arrays, *IEEE Transactions on Antennas Propagation*, Vol. 32, No. 10, pp. 1129–1133, 1971. doi:10.1109/TAP.1984.1143216.
7. S. K. Sanyal, Q. M. Alfred and T. Chakravarty, A novel beam switching algorithm for programmable phased array antenna, *Progress in Electromagnetic Research*, Vol. 60, pp. 187–196, 2006.
8. T. Chakravarty, S. H. Damle, J. V. Chande, S. Halder, K. P. Ray and A. Kulkarni, Calibration of ST radar using radio source Virgo-A, *Indian Journal of Radio and Space Physics*, Vol. 22, pp. 103–107, 1993.
9. Q. M. Alfred, T. Chakravarty and S. K. Sanyal, A novel schematic for calibration of large phased array antenna using programmable time-delay units, *Progress in Electromagnetic Research*, Vol. 65, pp. 81–91, 2006. doi:10.2528/PIER06080301.
10. M. I. Skolnik, *Introduction to radar systems*, Tata McGraw HillNew York, 2002.
11. P. M. Woodward and J. P. Lawson, A theoretical precision with which an arbitrary radiation pattern may be obtained from a source of finite size, *IEE Proceedings*, Vol. 95, pp. 362–370, 1948.
12. R. S. Elliott and G. J. Stern, Footprint patterns obtained by planar arrays, *IEE Proceedings*, Vol. 137, No. 2, pp. 108–112, 1990.
13. C. A. Balanis, *Antenna theory: analysis and design*, WileyNew York, 1982.

Author Biographies

Q. Md. Alfred obtained B.Tech (Electronics and Telecomm. Engg.) from IEM, Kolkata, India in 2000 and M.Tech (in Microwave Engg.) from University of Burdwan, West Bengal, India in 2002. He is pursuing Ph.D from Jadavpur University, Kolkata, India. He has worked as full time and guest faculty in various Engineering institutes from 2002. Presently holding faculty position in University Institute of Technology in Electronics and Comm. Engineering Department, University of Burdwan. His current interest includes phased array antennas, neural networks; image processing, bioinformatics and computational biology etc. Selected as *Marquis Who's Who in the World* in 2007 and 2009.

N. Chopra received B.Tech Degree in Electronics and Communication Engineering from Jaypee University of Information Technology in 2007. Currently, she is working as a Software Engineer in HCL Technologies (2007-till date). Her present interests include Antenna's.

T. Chakravarty holds a Ph.D degree from Jadavpur University with specialization in microstrip antenna design. Earlier he has completed M.Sc (Electronics Science) from South Campus, Delhi University. He has spent 15 years as Scientific Officer in SAMEER, a premier microwave research laboratory of Govt. of India. This stint was followed by three years in academics as Principal of a self-financed engineering college and a professor and member of academic council of Jaypee University of Information Technology, Himachal Pradesh. In SAMEER, he has executed a number of custom RF/Microwave projects like Indian MST Radar which is installed in Gadanki, a village near Tirupati, A.P. Tapas joined TCS in July 2007 as Senior Scientist in Embedded Systems Innovation Lab., Bangalore. Tapas have extensive experience in custom RF circuit and antenna design. He has to his credit, more than 90 numbers of peer-reviewed publications including 43 journal publications and 1 book chapter. He has supervised a number of M.Tech/B.Tech theses from three major universities of Bengal. He is also listed as Ph.D examiner in the ETCE department of Jadavpur University. Currently he is guiding a Ph.D thesis on programmable antenna array from Jadavpur University. Tapas Chakravarty is a member of IEEE, the member of joint chapter of IEEE AP-MTT, IEEE Communication Society and IEEE CAS society chapters under Calcutta section. His professional work has been recognized by listing him in Marquis Who's Who in the World.

G. Singh received Ph.D. degree in Electronics Engineering from Institute of Technology, Banaras Hindu University, Varanasi, India, in 2000. He was Visiting Researcher at the Seoul National University, Seoul, Korea. At present, he is an Assistant Professor with the Department of Electronics and Communication Engineering, Jaypee University of Information Technology, Solan, India. He has published more than hundred research articles in peer reviewed journals/conferences. His research interests include relativistic electronics, surface plasmons, electromagnetics and composite materials, nanophotonics, THz radiation devices and antennas.

S. K. Sanyal received his B.E.Tel.E, M.E.Tel.E and Ph.D (Engg.) degrees all from Jadavpur University in 1977, 1979 and 1990, respectively. He joined the Department of Electronics and Tele-Communications Engineering at Jadavpur University as Lecturer in 1982 where he is currently a Professor and Head. He has published more than 120 research papers in various international journals and conference proceedings. His current research interests include Digital Signal Processing, Tunable Microstrip Antenna, Wireless and Mobile Communication and VLSI circuits.