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# A Novel Wideband Subarray Technique for Shaped Pattern Generation and Adaptively Interference Rejection

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**Abstract** In this article, a simple and efficient technique for the wideband shaped beam and sector beam pattern generation with their adaptive interference rejection is proposed. A microcontroller controlled and time delay based beam forming network for simultaneously generating multiple beams, shaped beam and sector beam is conceptualized. The antenna patterns considered here is formed by linear array of isotropic elements grouped as subarray. The shaped and sector beam synthesis procedure is practically simplified by simultaneous adding the constituents beams from the subarrays, was theoretically established by Woodward and Lawson (Proc. IEE. 95(1):362–370, 1948). Apart from the shaped beam generation a technique for adaptive interference rejection in shaped patterns using combination of time delay and phase shifter is discussed. This topic promises good prospect for wideband pattern generation and interference rejection.

**Keywords** Phase array · Microcontroller · Radar · Bandwidth · Time-delay · Phase shifter

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## 1 Introduction

A persistent problem in designing wideband phased array system is that, due to frequency dependent squint, their bandwidth decreases with scan angle [2, 3].The only solution to the problem is using time delayers in place of the phase shifters in feed network. Tang [3], proposes phase shifters in the element level and time delay in the subarray level. But this paper proposes only time delay units in subarray level. Also Steyskal [4, 5] have shown that, exciting each antenna elements with complex phase and amplitude, shaped and sector beam pattern can be generated. This method is limited for practical implementation as it is complex and not cost effective. Instead here, beam peaks from each subarray are approximately added to avoid complexity. In this proposed scheme, twenty (20 nos) linear antenna elements grouped into five (5 nos) subarrays having four (4 nos) elements each and each subarray is fed by a beam forming matrix as shown in Fig. 1. The beam forming (steering) matrix shown here is a true time delay (delay line) based switching matrix and is controlled by a 16 bit microcontroller was shown earlier by the authors [1, 6, 7]. Antenna elements in the subarray are properly loaded with time delay units so that equivalent phase tapering is obtained to steer the beam in a desired direction. Multiple beams form the subarray sections are electronically

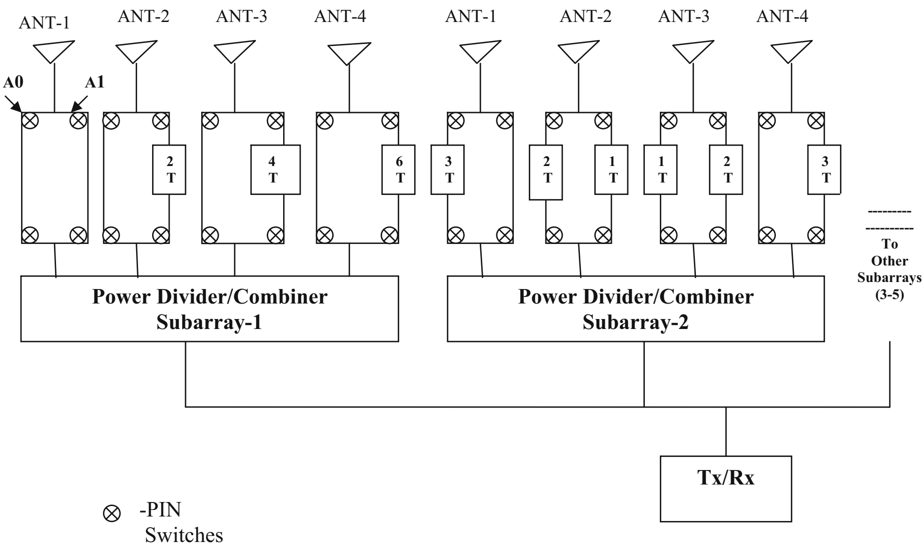


**Fig. 1** Subarrays for shaped and sector beam pattern generation.

**Table 1** Combination of time delays in subarrays (only subarray 1 and subarray 2 is represented).

| Switching pattern | | Subarrays-1 (Time delays given for elements) | | | | Delay gradient | Subarrays-1 (Time delays given for elements) | | | | Delay gradient |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A0 | A1 | element 1 | element 2 | element 3 | element 4 | | element 1 | element 2 | element 3 | element 4 | |
| 1 | 0 | 0 T | 0 T | 0 T | 0 T | 0 T | 3 T | 2 T | T | 0 T | −T |
| 0 | 1 | 0 T | 2 T | 4 T | 6 T | 2 T | 0 T | T | 2 T | 3 T | +T |

**Table 2** Switching pattern and beam formation by subarrays.

| Switching bit pattern | | Delay gradient | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $A_0$ | $A_1$ | Subarray 1 (Main beam angle) | Subarray-2 (Main beam angle) | Subarray-3 (Main beam angle) | Subarray-4 (Main beam angle) | Subarray-5 (Main beam angle) | Sum of Main Beam Position) | Resultant Pattern |
| 1 | 0 | 0 T (90 deg) | −T (82 deg) | −3 T (65 deg) | −5 T (46 deg) | −7 T (13.5 deg) | (90+82+65+46+13.5) deg | Cosecant type pattern |
| 0 | 1 | +2 T (106 deg) | +T (98 deg) | 0 T (90 deg) | −T (82 deg) | −2 T (74 deg) | (106+98+90+82+74) deg | Sector pattern |

Unit delay $T = \pi/8$. Inter element spacing d=0.4λ.

controlled in beam forming in the desired shape and sector. When one subarray beam overlaps the adjacent subarray beams, the null can not be formed but an envelope of antenna pattern is obtained with crossover level above - 4dB. Here, the generation of two representative shaped beams, cosecant type and sector beam is proposed.

## 2 Schematic and its implementation for pattern synthesis

In reference to Fig. 1, the proposed system comprised of five subarray section and each subarray has four antenna elements. Individual antenna elements are loaded with appropriate delay gradients in order to provide two set of phase gradient in between subarrays. They are:

$0T, -T, -3T, -5T$ and $-7T$ for cosecant type (shaped beam) pattern and
$+2T, +T, 0T, -T$ and $-2T$ for sector pattern generation.

where T is the time delay unit and should be chosen appropriately. Each element is connected with two switched delay line which is programmable by microcontroller. For high frequency application, PIN diodes acts as double pole double throw (DPDT) switches and at any instant only one path is switched on.

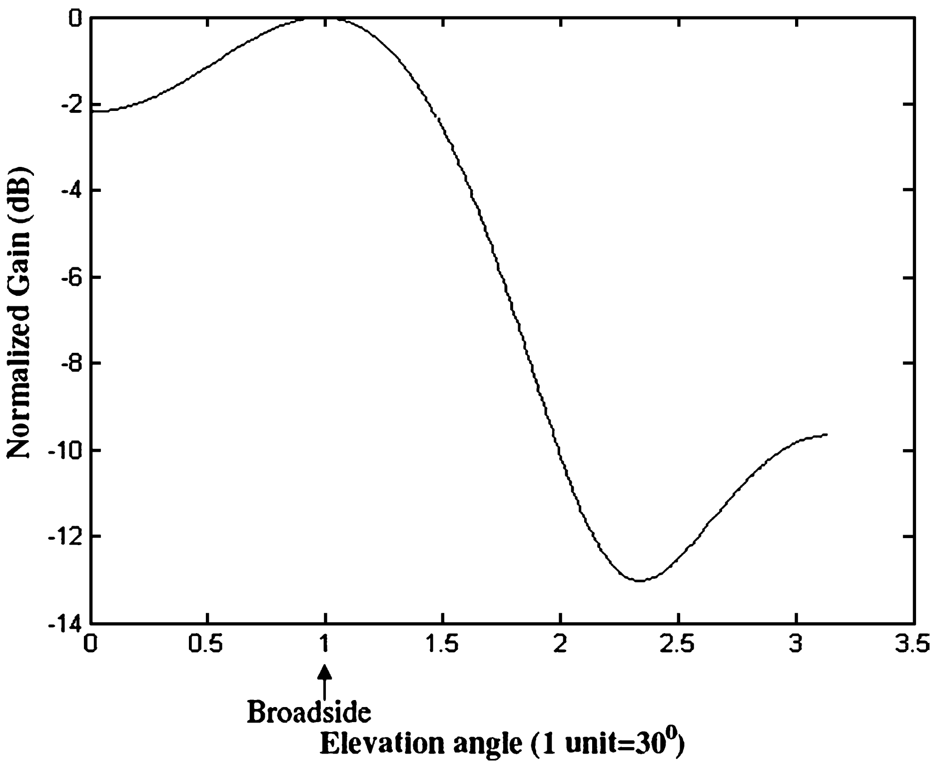


**Fig. 2** Cosecant type shaped beam (simulated result).

### 2.1 Case 1

Let us consider the situation, when the switching pattern $A_0 = 1$, $A_1 = 0$, then the delay gradient is zero between the elements in subarray 1 as shown in Table 1. In this type of switching pattern main beam will be in broadside direction (90°) from subarray 1. Simultaneously, in subarray 2 (at switching pattern $A_0 = 1$, $A_1 = 0$), delay gradient is – T as shown in Table 1 or beam will be steered in the direction 82° or 8° of elevation angle (eastward) as per following equation:

$$AFS(\theta) = \frac{\sin(N\psi/2)}{N\sin(\psi/2)} \tag{1}$$

where AF is the array factor and $\psi = kd\cos\theta + \beta$. N is the number of elements with separation d. β is the progressive phase difference and k is propagation constant.  is the elevation angle. In this way, the delay gradients −3T, −5T and −7T can be achieved respectively, for other subarrays 3, 4, 5 as shown by the Table 2. Ultimately, overlapping main beams from the subarrays result in null free cosecant type shaped pattern shown in Fig. 2.

### 2.2 Case 2

Consider the other switching position, $A_0 = 0$, $A_1 = 1$. In subarray 1, the delay gradient is +2T as shown by Table 1 or the main beam will be in 106° or 16° of elevation angle

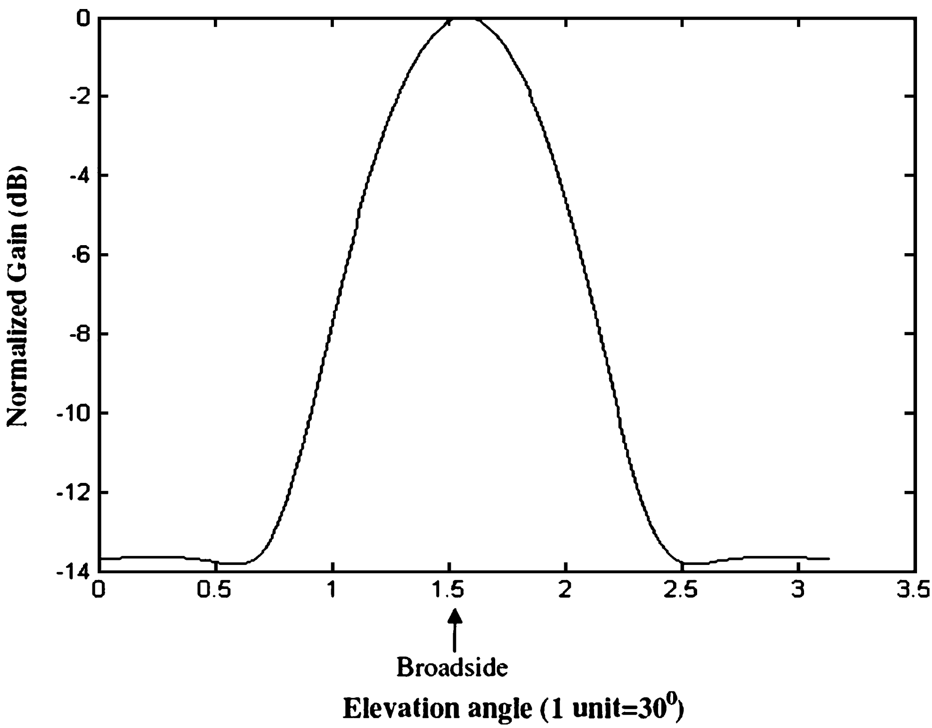


**Fig. 3** Sector beam (simulated result).

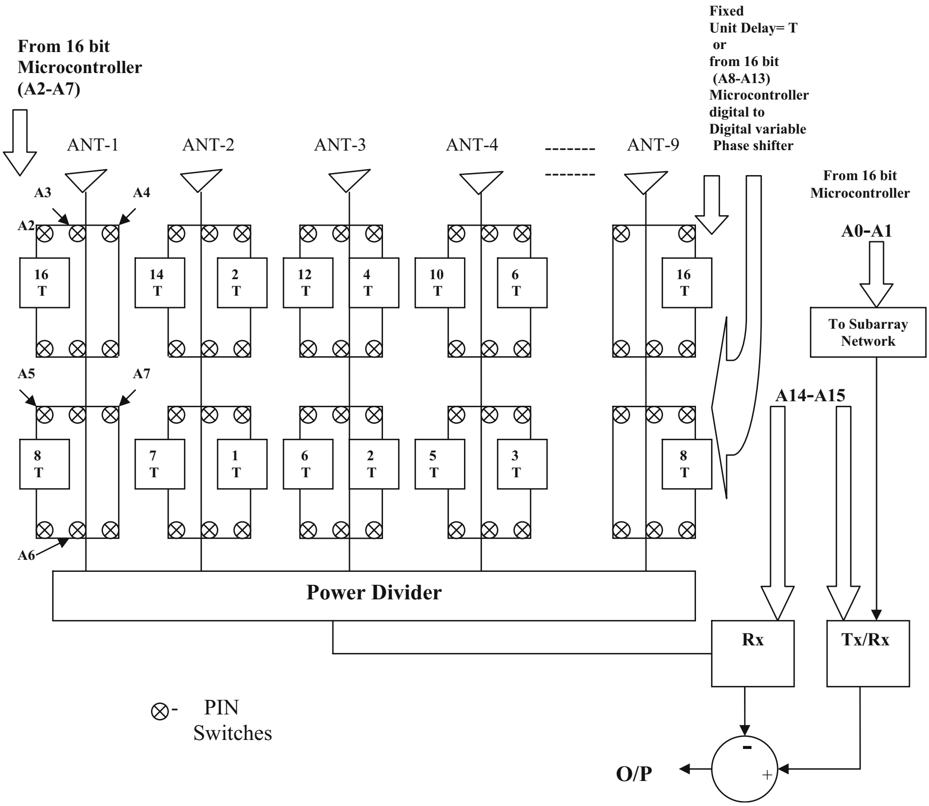


**Fig. 4** Switching matrix for cancellation beam pattern generation.

**Table 3** Representation of switching pattern, time delays, and delay gradient and cancellation angle in cosecant type shaped pattern

| Unit delay | Switching pattern | | | | | | Time delays in antenna elements | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\pi/6$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | Ant 1 | Ant 2 | Ant 3 | Ant 4 | ... | Ant 9 | Resultant Delay Gradient (rad) | Cancellation angle (from endfire) |
| | 0 | 1 | 0 | 0 | 1 | 0 | 0 T | 0 T | 0 T | 0 T | ... | 0 T | 0 T (0) | 90 deg |
| | 0 | 1 | 0 | 1 | 0 | 0 | 8 T | 7 T | 6 T | 5 T | ... | 0 T | −T(n/6) | 84 deg |
| | 1 | 0 | 0 | 0 | 1 | 0 | 16 T | 14 T | 12 T | 10 T | ... | 0 T | −2 T($\pi/3$) | 76 deg |
| | 1 | 0 | 0 | 1 | 0 | 0 | 24 T | 21 T | 18 T | 15 T | ... | 0 T | −3 T($\pi/2$) | 69 deg |
| $\pi/8$ | 0 | 1 | 0 | 0 | 1 | 0 | 0 T | 0 T | 0 T | 0 T | ... | 0 T | 0 T(0) | 90 deg |
| | 0 | 1 | 0 | 1 | 0 | 0 | 8 T | 7 T | 6 T | 5 T | ... | 0 T | −T($\pi/8$) | 85 deg |
| | 1 | 0 | 0 | 0 | 1 | 0 | 16 T | 14 T | 12 T | 10 T | ... | 0 T | −2 T($\pi/4$) | 80 deg |
| | 1 | 0 | 0 | 1 | 0 | 0 | 24 T | 21 T | 18 T | 15 T | ... | 0 T | −3 T($3\pi/8$) | 75 deg |

Inter element separation d=0.7λ.

(westward) from broadside. At this switching pattern, the other delay gradients in subarrays are +T, 0,−T and −2T as shown by Table 2. All the beams overlaps to form sector beam as shown in Fig. 3.

## 3 Concept for interference rejection

The conceptual development is now extended to deal with interference rejection in a predefined angle. In the case of search radar (cosecant pattern) interference comes deliberately from electronic jammers. So there is a need of adaptive pattern nulling in the direction of the interference in the shaped region or sector region. Adaptive nulling by phase only control has been proposed in literature [8–11]. In this paper, we have conceptualized this by considering an auxiliary linear array of 9 element with inter-element spacing d = 0.7λ. Microcontroller controlled delay matrix [12] steers the resultant beam in the direction of arrival (DOA) of the unwanted signal and is referred here as cancellation beam. By adaptively steering the cancellation beam null is produced in the direction of undesired signal. Figure 4 shows the schematic of the concept. To establish the concept, simple switching matrix in Fig. 4 steers the cancellation beam only in the seven angular location providing inter-element delay gradient of 0T, +T, +2T, +3T and −T, −2T, − 3T. To achieve cancellation in the far field, first all the cancellation array element are phase shifted by 180° or equivalently six unit of delay(delay line), then they are fed by proper delay gradient in order to steer the cancellation beam adaptively in the DOA of unwanted source. Mathematically, we can show the cancellation beam [13, 14].

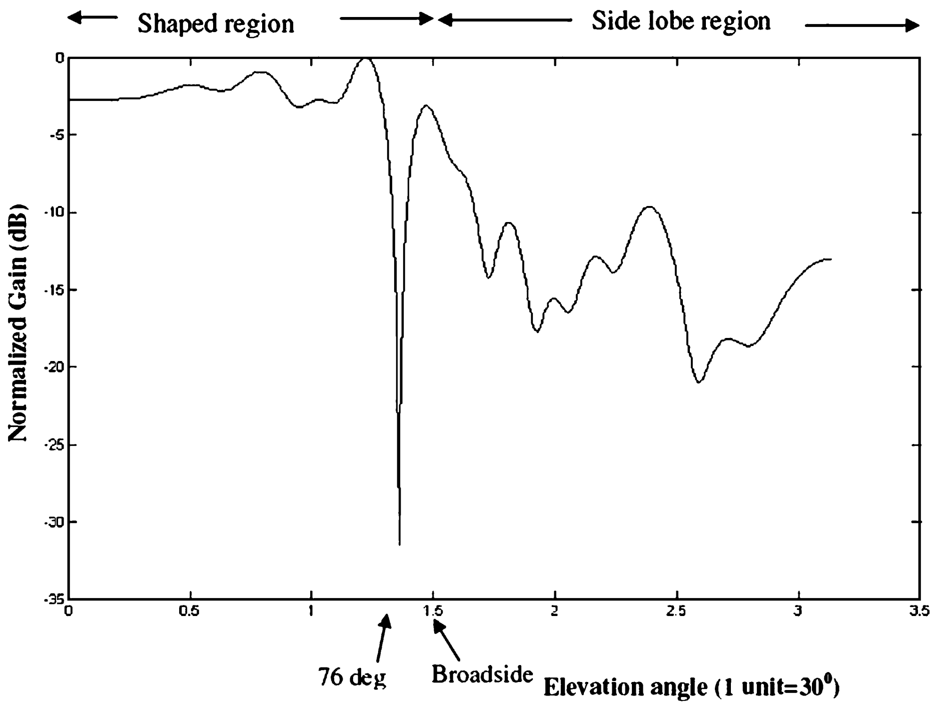


**Fig. 5** After interference cancellation at 76° (simulated) in shaped region of Fig. 3.

$$AF_c(\theta) = \Sigma a_N \exp(-jN\psi) \exp(-jNT1) \tag{2}$$

Here N = 0 to 8, $a_0 = a_1 = a_2 = a_3 = a_6 = a_7 = 1$ and $a_4 = a_5 = 2$

Resultant pattern in the far field can mathematically be expressed as following.

$$\begin{aligned} AF_R(\theta) &= AF_S(\theta) + \exp(-j\pi)AF_c(\theta) \\ AF_R(\theta) &= AF_S(\theta) - AF_c(\theta) \end{aligned} \tag{3}$$

Number of antenna elements in cancellation array is simply chosen as per with the power level in shaped or sector region.

Table 3 shows the details of unit delay, delay gradient and angle of interference cancellation when unit delay is fixed to $T=\pi/6$. Instead of fixed delay line as 'unit delay' it can be replaced by voltage controlled variable phase-shifters. Consider the situation when $T=\pi/8$, the resultant delays and angle of cancellation is shown in Table 3.

Figure 5 shows the interference cancellation at an angle 76° in shaped region of the cosecant type pattern. It is seen that the cancellation is of the order of −33 dB. In another example, Fig. 6 shows interference rejection at 69°, or 21° away from broadside. Here the cancellation order is same as before.

Similarly, in sector pattern, interference can be rejected in DOA angle. Figure 7 shows the interference cancellation in the far field for sector pattern at 85° when delay gradient T=−π/8 and element separation d=0.7λ. This delay can be well obtained when unit delay T= π/8 in beam switching matrix. Figure 8 shows the interference cancellation in the far

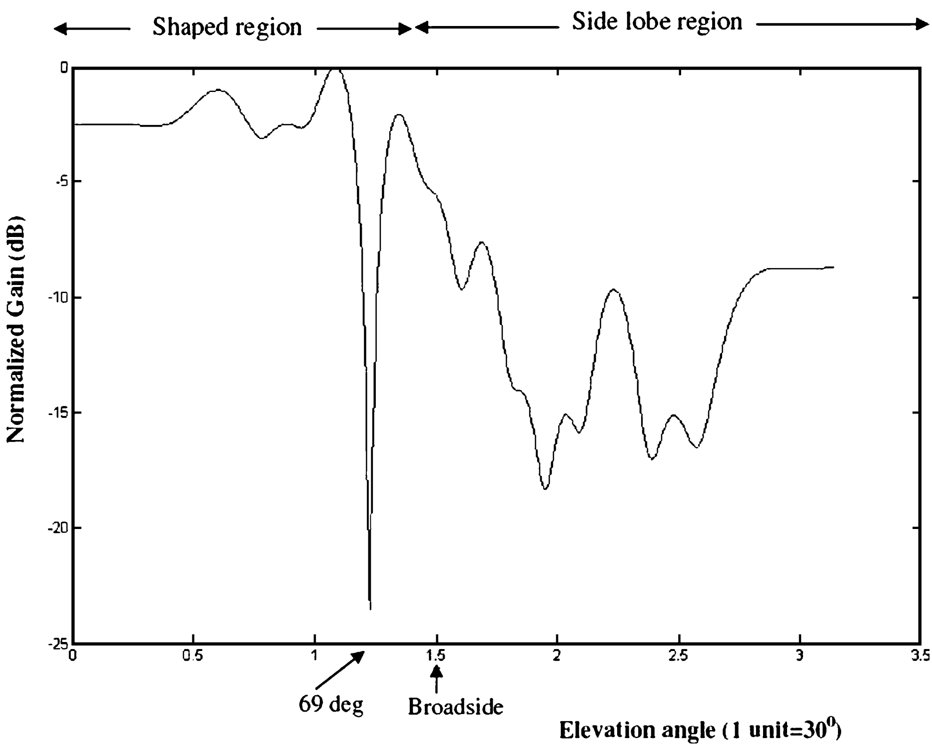


**Fig. 6** After interference cancellation at 69° in shaped region of Fig. 3 (simulated result).

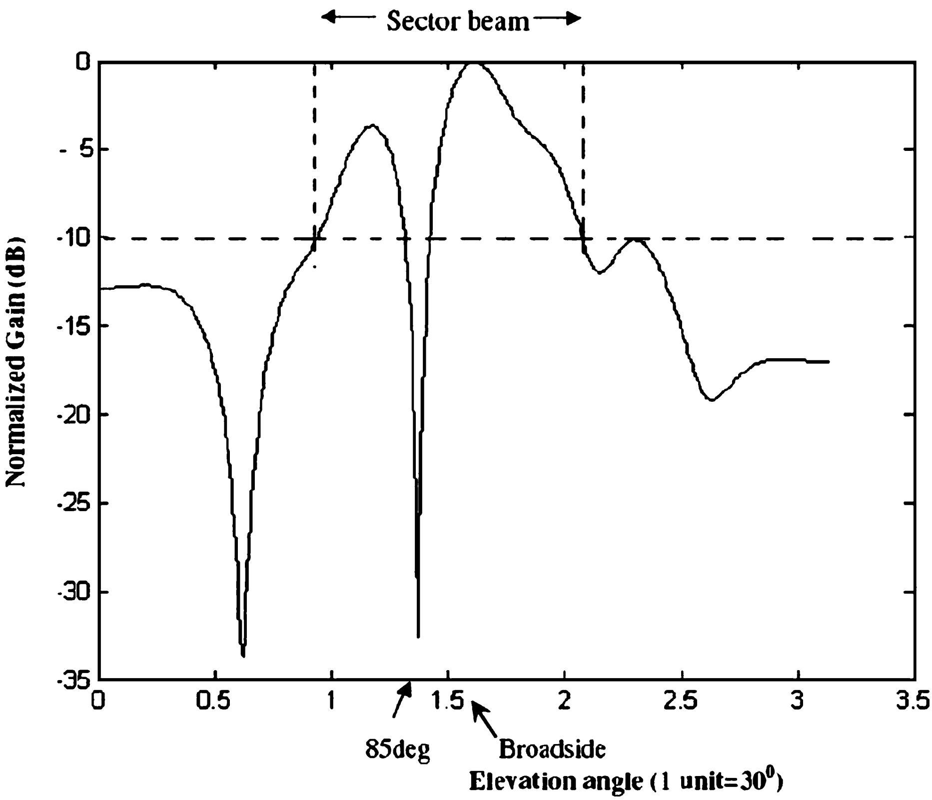


**Fig. 7** After Interference cancellation at 85° in sector region of Fig. 4 (simulated result).

field for sector pattern at $95^0$ when delay gradient $T=+\pi/8$, element separation $d=0.7\lambda$, unit delay $T=\pi/8$. Figure 9 Shows the interference cancellation in the far field for sector pattern at 90° when delay gradient $T=0$, element separation $d=0.7\lambda$, unit delay $T=\pi/8$.

## 4 Discussion

In this paper, a simple to implement and efficient method of generation of wideband shaped beams and a method for adaptive interference cancellation has been discussed. The simulation tools used assume ideal conditions. One needs to understand the effect on the schematic for non-ideal conditions like true time delay errors which may be random to each other but fixed upon installation. Also, the losses need to be accounted. It is envisaged that instead of making an attempt to identify and quantify such errors, it is better to periodically calibrate the phased array. Such a calibration technique is discussed by the authors in [7]. The required phase offsets can be introduced in the system after the signal is received to account for random errors in hardware. One of the standard propositions for adaptive interference cancellation is by utilizing weighting coefficients in the amplitude part of array. In this paper, however, only the phase components are utilized; that too in a well defined quantized unit of "T" for such generation. It can be understood that if a synthesis mechanism of such adaptive cancellation is developed based on the simple job of switching

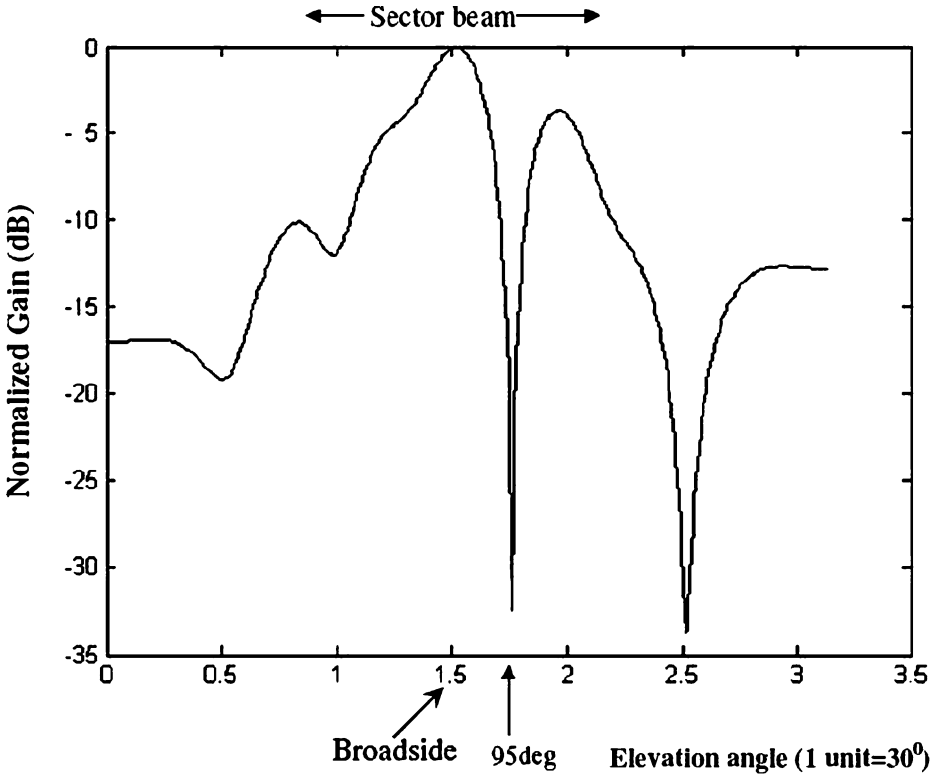


**Fig. 8** After Interference cancellation at 95° in sector region of Fig. 4 (simulated result).

on/off some pin diodes only (thereby inserting suitable phase gradients) then it brings about an entire new dimension to array synthesis. In [16], two antenna array phase-only controls are addressed. The problems are formulated as minimization of multi-dimensional functions. Author in [17] has outlined a design of a switched beam linear array in which two beams with specified shapes; one narrow beam and the other wide beam are to be produced. The beams are produced by phase-weight control only. There are a few more articles available for such phase-only control mechanism. Our definition of the present problem falls in the same sub-set.

One may also look into the effect of mutual coupling between adjacent elements. In one of the most cited publications on mutual coupling between microstrip patches [18], a measurement was conducted and the results published. For two circular patches with fundamental frequency of operation at 1440 MHz, a separation of 18 mm between edges (separation of 0.2 λ) leads to a mutual coupling value of −32 dB which is substantially low. For the present, a separation of 0.7 λ has been taken which is considered optimum for phased array applications.

## 5 Conclusion

A method of wideband phase-only controlled shaped beam pattern generation was discussed. The programmable time-delay based schematic can be used for many

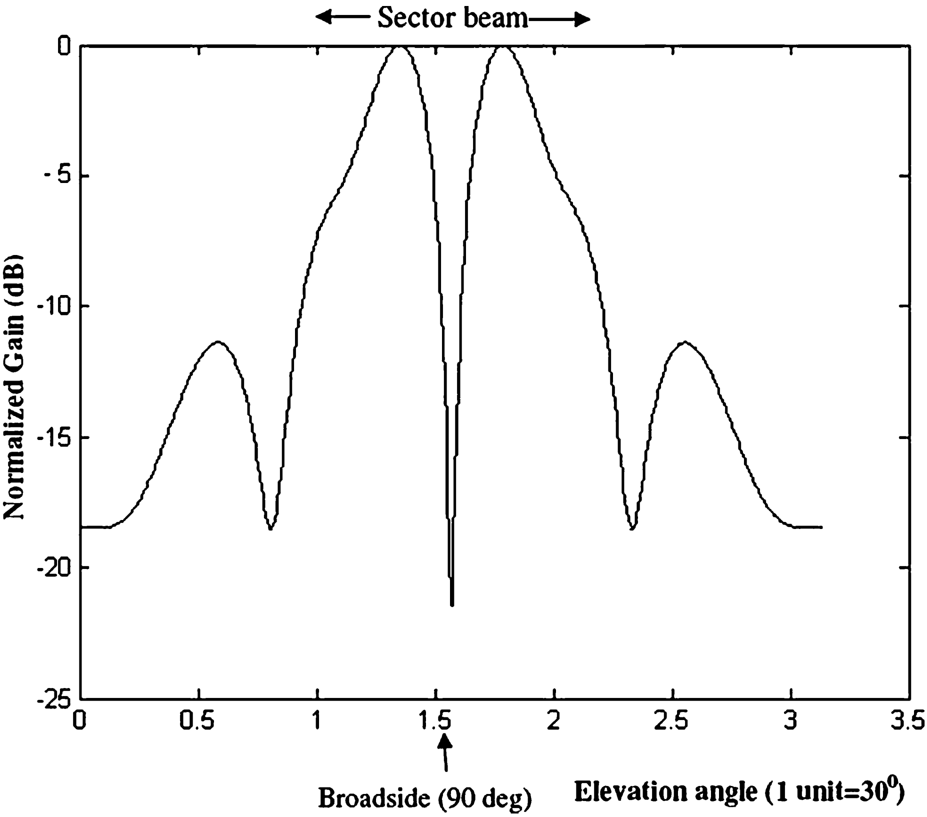


**Fig. 9** After Interference cancellation at 90° in sector region of Fig. 4 (simulated result).

applications like monopulse tracking [15]. In this paper, the method to generate shaped beams is presented along with its capability to cancel interference. Once the DOA of interference signal is estimated, suitable delay gradients can be introduced using a microcontroller based control systems to produce a null. In the case of interference rejection, more refinement can be obtained with this proposed method for side lobe nulling by controlling the power of cancellation array.

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