A DSP BASED STUDY OF PATTERN NULLING AND PATTERN SHAPING USING TRANSFORM DOMAIN WINDOW TECHNIQUE

Q. M. Alfred and K. Bishayee

Department of Electronics & Communication Engineering
University Institute of Technology
Burdwan, West Bengal, India

T. Chakravarty

Embedded Systems Innovation Laboratory
Tata Consultancy Services
Abhilash, Bangalore, India

S. K. Sanyal

Department of Electronics & Telecommunication Engineering
Jadavpur University
Kolkata, India

Abstract—This article aims to provide a novel and efficient technique for pattern shaping and null steering in the environment of unwanted interferences. This paper presents a DSP based method, where at first DFT coefficients are obtained from spatial domain sampling and then operating by suitable window function gives new set of DFT coefficients. IFFT(IDFT) over these coefficients provide complex weights which adaptively introduces null in the direction interference while keeping the main beam toward desired signal.

1. INTRODUCTION

In recent years, a significant increase in traffic load in mobile communication has resulted in hostile environment. In order to counter such problem pattern nulling is required in the direction of interference arrival. When the angle of interference(s) is adaptively known or

has some priori knowledge, then it is possible to provide null in that direction(s). Various research works in this area has been performed. Several adaptive and null steering methods (algorithms) are discussed in [1–20]. Among them some uses phase control methods [1–4], where only phase of the elements are adjusted properly to provide beam steering and simultaneously imposing null in interference direction. Some paper deals with pattern nulling by only amplitude control [5, 6]. All these method have their own advantages and disadvantages in terms of complexity, cost, bandwidth etc. These methods are suitable for interference cancellation but can not simultaneously provide different shaped patterns. In [7], a simple wideband subarray technique for simultaneous pattern shaping and pattern nulling is proposed. But with the advent of high speed digital signal processor, DSP based beam forming (beam shaping, pattern nulling, beam steering etc.) algorithms are now emerging trends. Wu et al. [8] have studied an interesting algorithm for pattern synthesis, where DFT and IDFT is adopted for different beam pattern realization.

In this communication authors have also proposed a DSP based novel technique for adaptively interference rejection and pattern shaping. Instead of using conventional time domain window [8], here it is proposed a novel transform domain (space domain) window for adaptive beamforming (pattern nulling, shaping etc.)

2. THEORETICAL OVERVIEW

In this paper a linear array of isotropic radiating elements ($K + 1$ nos.) having inter-element spacing of 'd' have been considered. Taking phase of the first element as reference, resultant antenna pattern in spatial domain can be represented by the following:

$$S(\theta) = \sum_{n=0}^{K} W_n \cdot \exp\left(-j \cdot \frac{2\pi}{\lambda} \cdot n \cdot d \cdot \cos(\theta)\right) \qquad (1)$$

where, W_n accounts for the weight assigned to the nth antenna element, λ is the wavelength and θ is the angle of arrival measured relative to array normal. Without loss of generality and to avoid grating lobe problem $d = \lambda/2$ is considered.

Now φ can be chosen as a variable so that, $\varphi = \pi \cos(\theta)$, then $\varphi \in [-\pi, +\pi]$ and the Eq. (1) reduces to the following.

$$S(\varphi) = \sum_{n=0}^{K} W_n \cdot \exp(-j \cdot n \cdot \varphi) \qquad (2)$$

Here in the expression of $S(\varphi)$, the inner terms of $[\exp(-j \cdot n \cdot \varphi)]_{n=0,\ldots,K}$ can be obtained as:

$$\int\limits_{-\pi}^{+\pi} \exp(-j \cdot n \cdot \varphi) \exp(j \cdot m \cdot \varphi) dx = \begin{Bmatrix} 2\pi, & m = n \\ 0, & m \neq n \end{Bmatrix} \qquad (3)$$

Equation (3) shows that $[\exp(-j \cdot n \cdot \varphi)]_{n=0,\ldots,K}$ from an orthogonal set within $\varphi \in [-\pi, +\pi]$.

Hence from the well known property of orthogonality, the weights (coefficients) of expression (Eq. (2)) can be calculated as follows:

$$W_n = \frac{1}{2\pi} \int\limits_{-\pi}^{+\pi} S(\varphi) \exp(j \cdot n \cdot \varphi) \, dx \qquad n = 0, 1, \ldots, K \qquad (4)$$

Here in this proposition, we have deliberately selected $W_n = 1$ (for uniform array) and then Eq. (2) is reduced by the following.

$$S(\varphi) = \sum_{n=0}^{K} \exp(-j \cdot n \cdot \varphi) \qquad (5)$$

Here actually, $S(\varphi)$ is space-domain Fourier Transform of radiation strength. Literally, it can be considered as Discrete Space Fourier transform (DSFT) analogous to its time domain counterpart, discrete-time Fourier transform (DTFT).

Now, as $S(\varphi)$ is continuous in the space domain, it is then sampled by N nos. of discrete samples for computational effectiveness, can be found by modifying Eq. (5), is given below .

$$S(k) = S(\varphi)\Big|_{\varphi = \frac{2\pi}{N}k} = \sum_{n=0}^{K} \exp\left(-j\frac{2\pi}{N} \cdot k \cdot n\right), \text{ where } 0 \leq k \leq N-1 \quad (6)$$

Equation (6) actually provides the DFT (Discrete Fourier Transform) of the quiescent pattern of the linear array. These DFT coefficients or $S(k)$ of the quiescent pattern are operated (e.g., multiplied) by some transform domain windows to generate a new set of DFT coefficients $S'(k)$. Now IDFT (IFFT) is performed over these modified set, which in turn yields the complex array weights $s'(n)$ and these weights are fed to the antenna elements to generate desired pattern, shown in Eq. (7).

$$s'(n) = \frac{1}{N} \sum_{k=0}^{N-1} S^{/}(k) \exp\left(+j\frac{2\pi}{N} \cdot k \cdot n\right), \text{ where } 0 \leq k \leq N - 1 \quad (7)$$

Application of these modified weights $s'(n)$ to each radiating element will generate the adapted array pattern, as given by the following expression:

$$S_a(\varphi) = \sum_{n=0}^{K} s'(n) \cdot \exp\left(-j \cdot \varphi \cdot n\right) \qquad (8)$$

where $S_a(\varphi)$, stands for adaptive array pattern. Hence the Eq. (8) is also a DSFT operation on the linear discrete array elements. These patterns are adaptive to avoid undesired interference and they also can be employed to some special purposes which are detailed in the following section.

3. SPATIAL WINDOW TECHNIQUE

Here the term 'window' signifies a suitably chosen matrix of real coefficients, operates over the DFT coefficients to modify quiescent pattern in desirable way.

These windows are operated in spatial domain for various pattern shaping purposes, can be highlighted by the following.

a) Rejection of unwanted interference(s) by adaptively imposing null(s) at the direction of interference arrival.

b) Pattern shaping in the environment of interference or generation of special purpose patterns like sector beam, cosecant beams etc.

Schematically, this procedure can be described as follows.
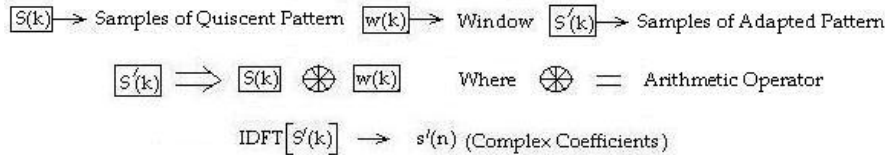
Realization of this method with the help of Matlab$^{\circledR}$ simulation is detailed in the following section.

4. PATTERN NULLING AND RESULTS

Overall response of the adaptive array pattern depends on the number and strength of the interfering signals. The results shown here are obtained at Matlab simulation environment. A linear array of $11(K =$

10) uniform isotropic antenna elements has been considered for all the situations discussed here.

Case-1 (single interference):

Let us consider a situation, where a single source of interference is arriving towards $\varphi = 0.27\pi$ (corresponding to 228th sample point) in the quiescent pattern as shown in Fig. 1.

To reduce the effect of interference, a pattern null to be imposed at the direction of interference arrival.
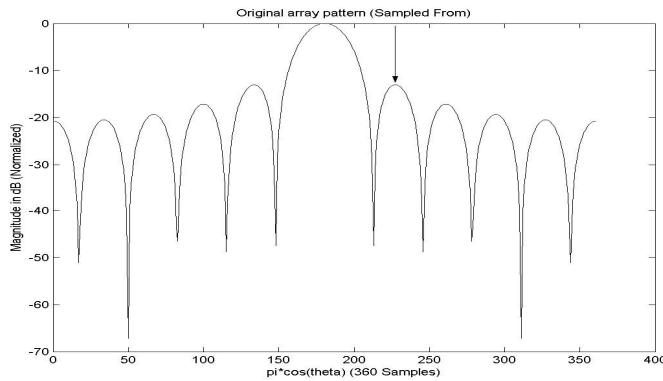

Figure 1. Quiescent pattern with a single interference at $\varphi = 0.27\pi$.

Under this null constraint, the quiescent pattern is adapted by the window technique. Here a window $w(k)$ is of equal size of DFT samples ($N = 360$) is selected, where first 213 samples having magnitude $+1$, next 21 samples are -1 and last 126 samples are $+1$, as depicted in Fig. 2.
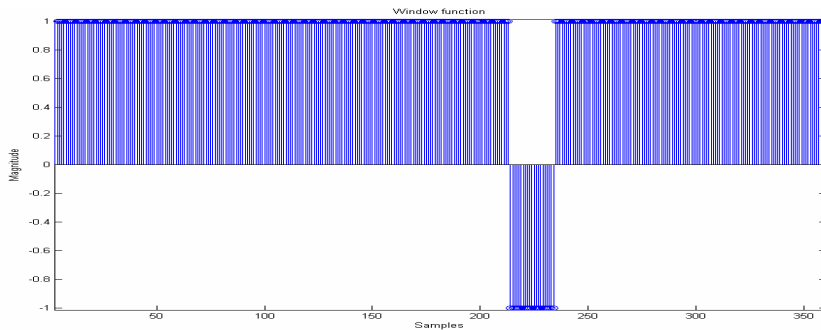
Figure 2. Selected window function ($N = 360$ samples).

After multiplication by this window to the original DFT coefficients $S(k)$, the nearest sidelobe region (RHS from broadside) is suppressed toward negative. Original DFT pattern (array pattern) and its adapted form (modified pattern) after windowing are depicted in Fig. 3.

After multiplication, a new set of DFT coefficient is hereby produced $S^{/}(k)$. Now IDFT is performed over $S^{/}(k)$, which yields a set of complex array coefficients $s^{/}(n)$. Amplitude and phase plot
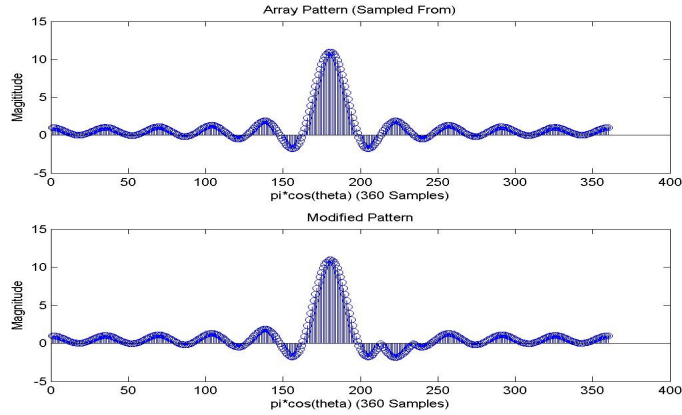

Figure 3. Original DFT pattern (array pattern) and its adapted form (modified pattern).
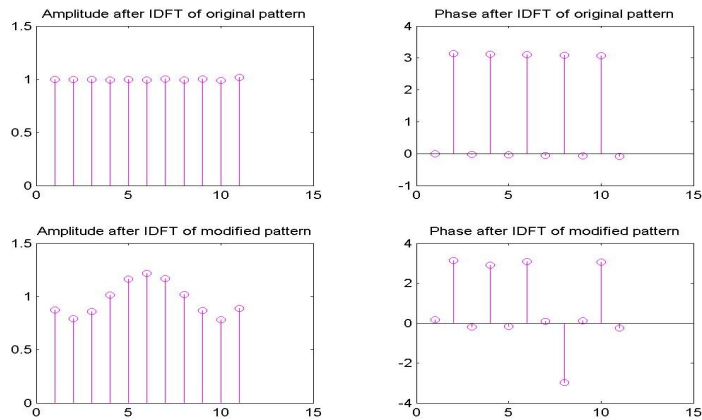
Figure 4. Comparative (w.r.t original array excitation) amplitude and phase plot of $s^{/}(n)$.

of this $s^/(n)$ is comparatively(w.r.t original array excitation) shown in Fig. 4.

Now the coefficients, $s^/(n)$ is fed to the array elements as complex weight vector , which produces the adapted null in the desired direction is shown in Fig. 4.

It is worthwhile to mention that, taking DSFT operation over these $s^/(n)$ coefficient produces adapted pattern(in Fig. 5).
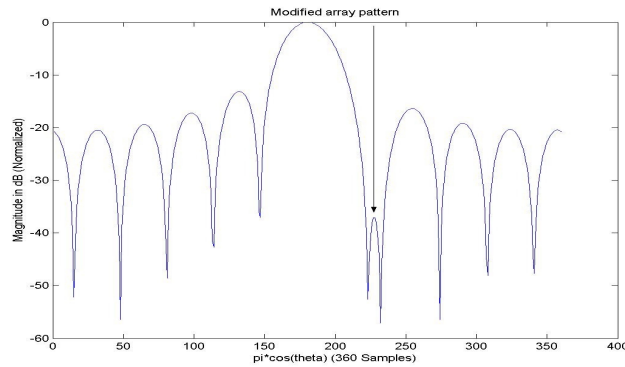

Figure 5. Adapted pattern in the interference direction.

Case – 2 (double interference):

Consider another situation, where two interferences are arriving from different direction shown (indicated by two arrows) in Fig. 6. Interferences are impinging on quiescent pattern on both the sidelobes at the angles $\varphi = 0.73\pi$ and $\varphi = -0.27\pi$ (132nd and 228th sample points) respectively.
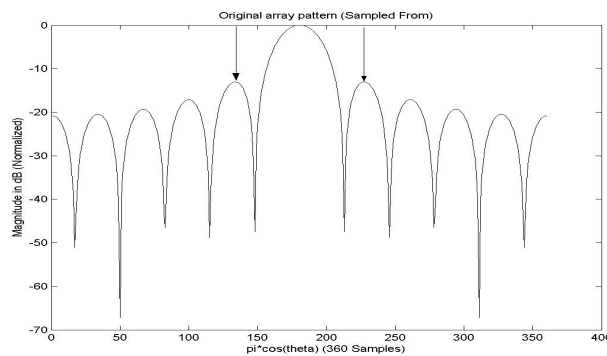

Figure 6. Quiescent pattern with a double interference at $\varphi = 0.73\pi$ and $\varphi = -0.27\pi$.

Similarly, original DFT pattern $S(k)$ and adapted pattern $S^/(k)$ (after multiplication with proper window) is as shown in Fig. 7.
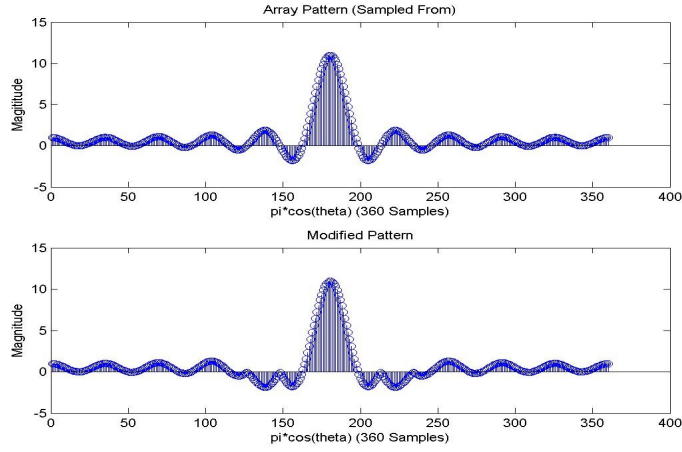

Figure 7. Original DFT coefficient (array pattern) and its adapted form (modified pattern).

Figure 8 depicts amplitude and phase plot of resultant complex coefficient $s^/(n)$ after performing IDFT.
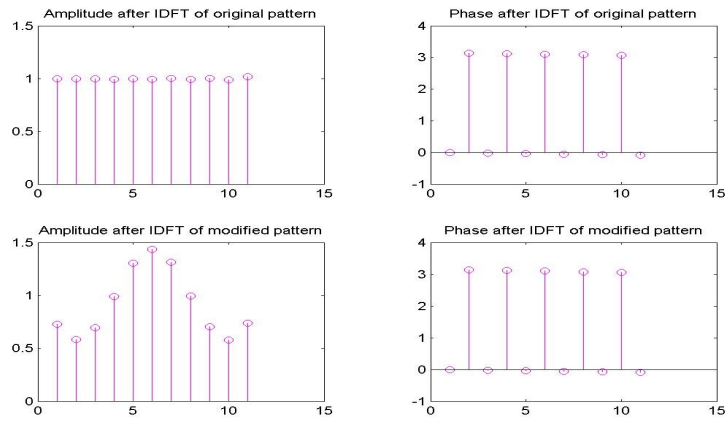

Figure 8. Comparative (w.r.t original array excitation) amplitude and phase plot of $s^/(n)$.

Ultimately, these coefficients provide complex weighting function, which generates two pattern nulls in desired directions (Fig. 9).
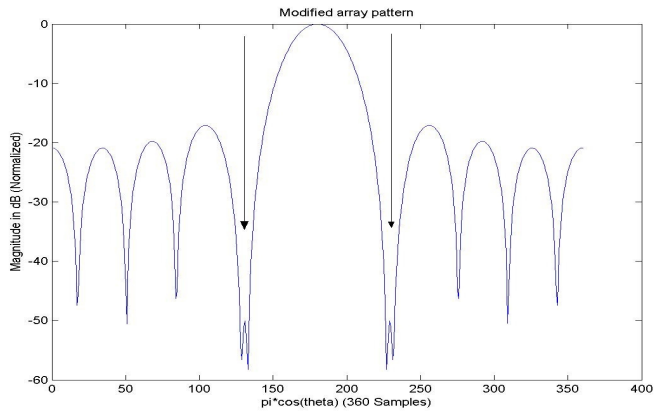
Figure 9. Adapted pattern in the interference direction.

Case – 3 (multiple interference):

This procedure can be applied to reduce the effect multiple interferences by choosing appropriate window. It is assumed here that the interferences coming along various direction, they are at $\varphi = 0.55\pi$, $\varphi = 0.73\pi$, $\varphi = -0.27\pi$ & $\varphi = -0.45\pi$.

Figure 10 shows the quiescent and adapted DFT coefficient before and after windowing respectively. Fig. 11 gives amplitude and phase plots of the complex weights. Fig. 12 shows the resultant pattern imposed over quiescent pattern.
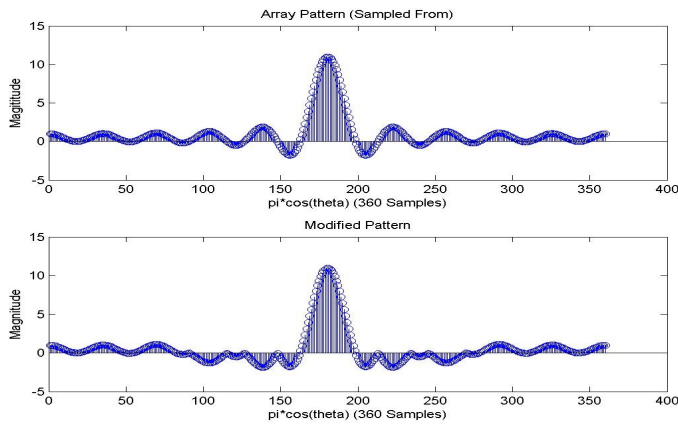

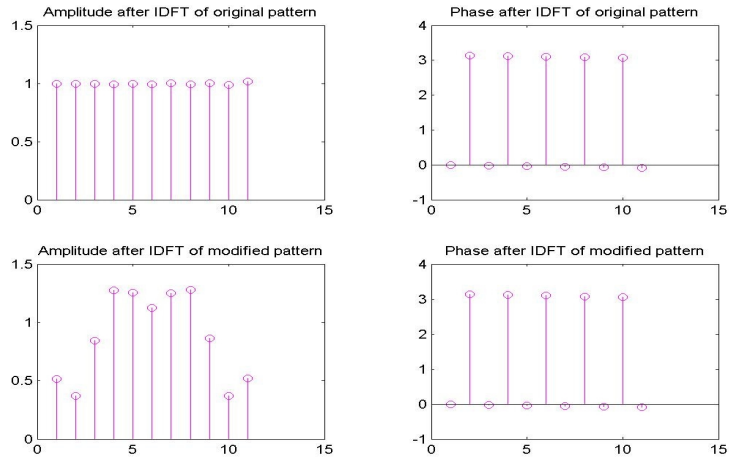**Figure 10.** Original DFT coefficients and its adapted form (modified pattern).

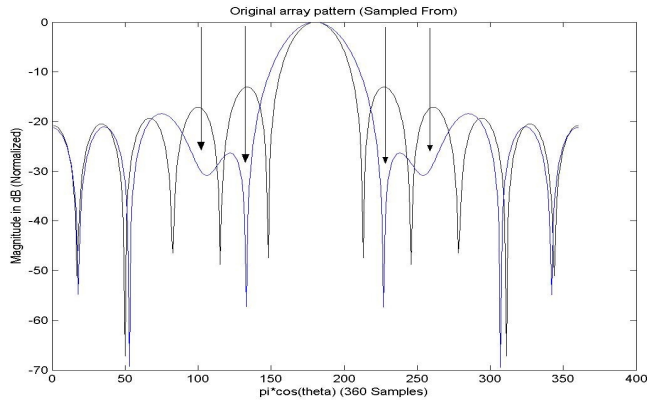**Figure 11.** Amplitude and phase plot of the complex weights.

Figure 12. Adapted pattern in the environment multiple interference. (Both the quiescent and adapted beams are superimposed on each other).

5. PATTERN SHAPING AND RESULTS

This may also proved to be an efficient technique for special purpose pattern generation. For example, Low-sidelobe sum pattern, sector pattern, cosecant pattern etc. They are needed for some special purposes in aviation, wireless communication etc.

For shaped pattern generation, the same linear array of 11 nos. of elements is considered. Here the generation of following two

representative shaped patterns is briefly discussed.

Low-sidelobe sum pattern:

Low sidelobe sum pattern is widely used in search radars. To generate such pattern, transform domain window $w(k)$ is chosen in such a way, that after multiplication with original DFT coefficients $S(k)$, all the side lobes except the main lobe produces negative lobes.

In Fig. 13 DFT samples of the quiescent pattern and its windowed DFT coefficient are shown.
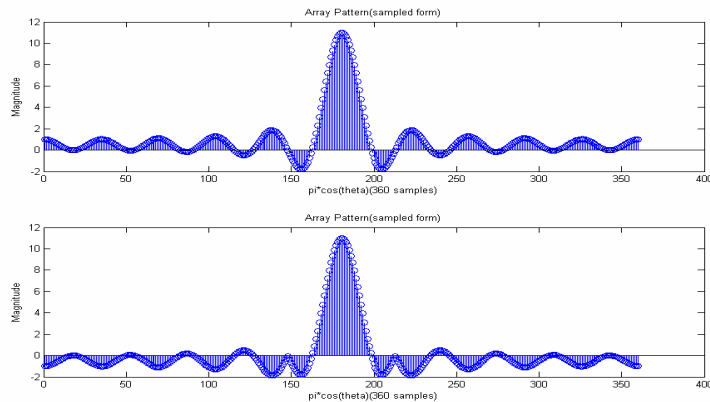
Figure 13. Original DFT coefficient and its adapted form (modified pattern).

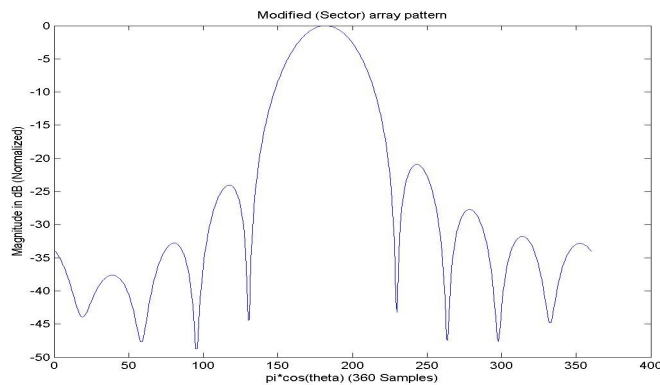Figure 14 depicts the resultant sum pattern with suppress sidelobe levels.

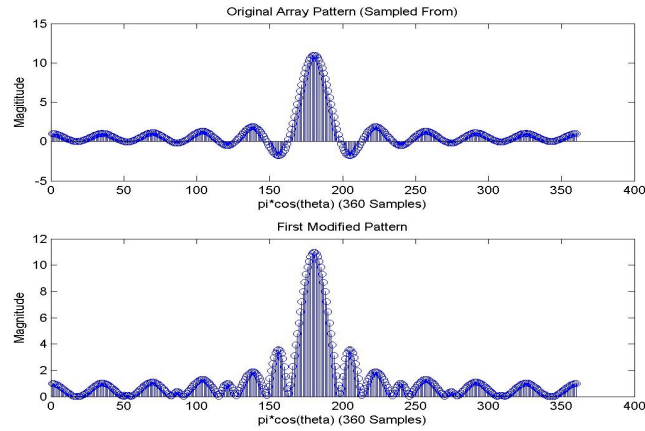**Figure 14.** Shaped sum pattern with low sidelobes.

Figure 15. Original DFT coefficient and its adapted form (modified pattern) after applying Ist window $(w^/(k))$.
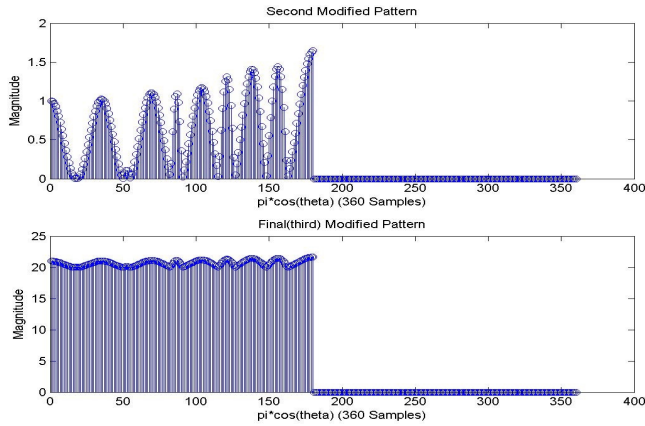

Figure 16. Original DFT coefficient and its adapted form (modified pattern) after applying 2nd $(w^{//}(k))$ and 3rd window $(w^{///}(k))$ respectively.

Cosecant-type Pattern Generation:

Another special purpose pattern is cosecant pattern, which is essential in air-traffic surveillance.

To generate a sort of cosecant pattern, three transformed domain windows is judiciously chosen here and operated in three steps, they
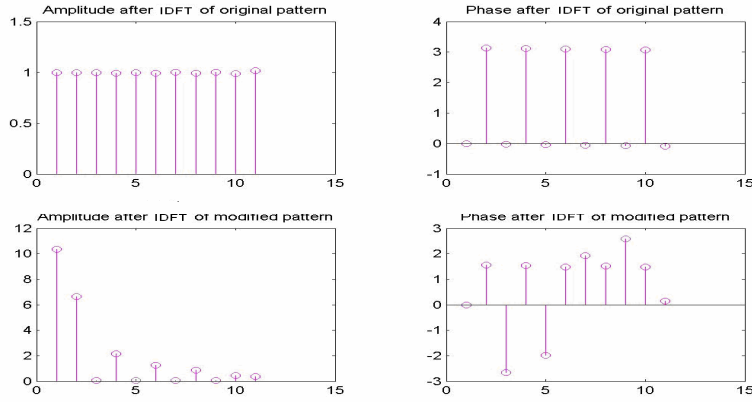
Figure 17. Amplitude and phase plot of the complex weights for cosecant type pattern generation.
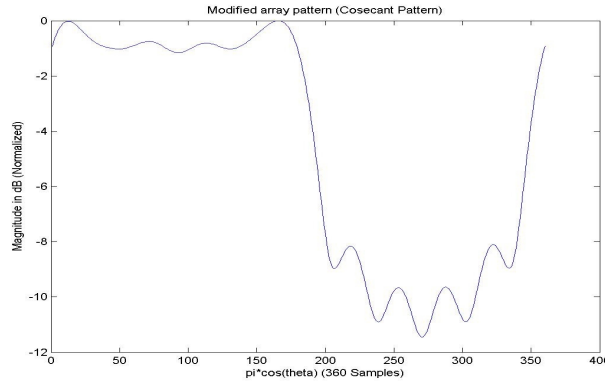

Figure 18. Generated Cosecant type pattern.

are $w(k)$, $w^/(k)$ and $w^{//}(k)$ respectively, can be shown by following.

$$S^/(k) = w^{//}(w^/(w(S(k)))) \tag{9}$$

Firstly, the window $w(k)$ is multiplied with original DFT coefficients $S(k)$, then all the negative coefficient becomes positive (Fig. 15). Then after multiplication with second window $w'(k)$, right half portion of the pattern is forced to zero value (Fig. 16). Finally, the third window $w''(k)$ is used to raise the magnitude of the coefficients (Fig. 16).

Now, IDFT is performed over the finally modified set of coefficients $S'(k)$, generates complex spatial coefficients $s^/(n)$. Amplitude and

phase plot of the complex coefficient for original pattern and the shaped pattern can be shown as below (Fig. 17).

Figure 18 indicates the generated shaped pattern using the complex IDFT coefficients.

6. CONCLUSIONS

This paper premises the method of pattern nulling and pattern shaping using spatial (transform) domain window technique, which is simple than the time domain counterpart. Here in the course of computation, Matlab simulation is effectively exploited for spatial domain sampling or to get DFT coefficients. Inverse Fast Fourier Transform (IFFT) is adopted for faster results than normal IDFT.

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