Adaptive Beamforming Using Subarrays

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Abstract—*Phased array antenna has a main role in multifunction radars used for multiple target tracking. Phased array antennas have a flexibility of performing digital beam forming and array processing. Adaptive nulling is one of the aspects in array processing to reduce the interference effect on the sensor performance. Array processing for large arrays at element level increases complexity of the system. System complexity is reduced by dividing the full array in to sub arrays. Adaptive beam forming has the close relation with sub array configuration. In this paper the effect of the sub array configuration on adaptive beam forming and grating notches has been explained in detail with the simulation results for ULA, However concept can be extended to planar array also.*

Keywords—subarray,grating notch,Adaptive beamforming.

1. INTRODUCTION

Beam forming is a method of combining several antenna elements coherently to provide directivity; hence it can be called as a spatial filter. In application like radar, side lobe interference will be suppressed by using the auxiliary antennas. Multipleauxiliary antennas are required to mitigate multipleinterference. Adaptive beam forming can mitigate multiple interferences without separate auxiliary antennas.Adaptive digital beam forming at element level needs higher computational power and increases the system complexity. To reduce the complexity radar designers performs beam forming by using sub array data.

In phased array technology there are different methods to scan the beam. Simultaneous Multi-beam generation using an antenna array has many advantages in radar applications. Multibeam generation by using RF beam forming is discussed [1].Multi-beam formation with digital beam forming offers advantages for multifunction radar applications[2].

Digital beam forming at element level not only needs higher computational power and also increases the system complexityand cost for large array. To reduce the complexity of the system multiple elements can be combined at RF level and few sub arrays outputs can be digitized and used for beam forming.

Past few decades there is a research of interest on array processing and the adaptive beam forming. Adaptive beam forming has many algorithms for interference suppression and discussed[3].The details of the algorithm which is used in this paper will be discussed in Section-II.The importance of the partial adaptive arrays for real-time applications are discussed in literature [4]-[5] .Designing of sub arrays for adaptive beam forming and its properties needs to be analyzed for array processing applications [6].The Adaptive beam forming using the sub-array outputs, need not have the knowledge of the complete array, only gains and the phase centers of the sub arrays areenough to compute the array manifold vector and the adaptive beam forming weight.

In this paper adaptive beam forming for linear array at sub array level with regular sub arrays is presented. The effect of grating notches on the original main lobe has been discussed with simulations. The irregular sub arrays are used to reduce the grating notches, transforming the regular sub arrays into irregular sub arrays has been discussed.

The structure of the paper as follows: explanation of the adaptive beam forming algorithm by using sub arrays, Antenna element and sub-array configurations for simulations and finally discussions on the simulation results followed by conclusions.

2. SUBARRAY LEVEL ADAPTIVE BEAMFORMING

First, discussion will be on adaptive beam forming at element level and then transform the same for regular sub arrays and finally combine this regular sub arrays into master irregular sub arrays as shown in figure 1.

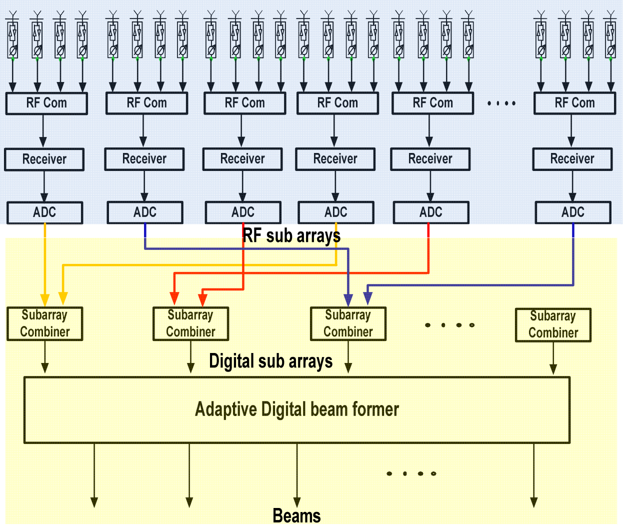

Fig. 1. *: Sub array Configuration for Adaptive beam forming*

One dimensional array has been considered, which can steer the beam by changing the phase values of the each element. The inter element spacing is assumed as half wavelength. Assume that there are N incoherentinterference impinging on array from far-field direction of $(\theta_n)$where the bore-sight of the array is (θ_0).The output of the lth (l = 1,2.....L) element, by assuming first element as reference is

$$x_l(t) = g_l \sum_{n=1}^{N} s_n(t) \exp\left\{-j\frac{2 * \pi}{\lambda}[(x_l - x_1)(\alpha_n - \alpha_0)]\right\} + n_l(t)(1)$$

Where

$$\alpha_n = \sin\theta_n, \alpha_0 = \sin\theta_0$$

g_l is the gain of the element. Each element is assumed as Omni-directional elements and without tapering. The antenna is divided in to P number of non-overlapped sub arrays. $J_n(t)$is the nth incident interference,$n_l(t)$ is the white Gaussian noise in the lth element.

Now we construct a Transformation matrix (T-matrix) from element level to regular sub array level. It has a dimension of *P X L,* whereP is the number of sub arrays. Matrix will have zeros and ones. Ones are present in a particular row (sub array) for a given column (element).

From (1) we can obtain sub array output vector as

$$X(t) = Tx(t) \qquad (2)$$

Where

$$X(t) = [X_1(t)\ , X_2(t), \dots\dots\dots\dots X_P(t)] \qquad (3)$$

The sub array phase centers are γ_p and gain of the p^{th}sub array are given by (4), (5) and (6) respectively.

$$\gamma_p = \frac{\sum_{l \in U_p} g_l\, x_l}{\sum_{l \in U_p} g_l} \qquad (4)$$

$$G_p = \sum_{l \in U_p} g_l \qquad (5)$$

Since tapering is not applied and each element is a Omni-directional element, gain will be unity, then the above equations (4),(5) can be replaced with (6) and (7)

$$\gamma_p = \frac{\sum_{l \in U_p} x_l}{Q} \qquad (6)$$

$$G_p = Q \qquad (7)$$

Where, *Q* is number of elements in the sub array.

Now construct a Transformation matrix (T_M-matrix) from regular sub array level to master irregular sub array level. It has a dimension of *K X P,* whereP is the number of regular sub arrays and K is the number of master irregular sub arrays. we can obtain master irregular sub array output vector as

$$Y(t) = T_M X(t) \qquad (8)$$

Where

$$Y(t) = [Y_1(t)\ , Y_2(t), \dots\dots\dots\dots Y_k(t)] \qquad (9)$$

The master sub array phase centers are γ_m and gain of the k^{th}sub array are given by (10) and (11) respectively.

$$\gamma_m = \frac{\sum_{p \in U_k} G_p\, \gamma_p}{\sum_{p \in U_p} G_p} \qquad (10)$$

$$G_m = \sum_{p \in U_k} g_p \qquad (11)$$

For a given angle θ, the array manifold vector is

$$A(\theta) = [a_1(\theta)\ , a_2(\theta), a_3(\theta) \dots\dots\dots\dots a_k(\theta)](8)$$

Where

$$a_k(\theta) = G_k\, exp\left\{-j\frac{2*\pi}{\lambda}[(\gamma_{m_k} - \gamma_{m_1})(sin\,\theta - \alpha_0)]\right\}(9)$$

Sample Matrix Inversion (SMI) is used as a adaptive beam forming method. The correlation matrix $(\hat{R}_{i+n})$ is estimated with k samples as

$$\hat{R}_{i+n} = \frac{1}{k}\sum_{i=1}^{k} X_{i+n}(n_k) X_{i+n}^{H}(n_k) \qquad (10)$$

The adaptive beam forming weights[12] are

$$W = \frac{\hat{R}_{i+n}^{-1} A(\theta_0)}{A^H(\theta_0)\hat{R}_{i+n}^{-1} A(\theta_0)} \qquad (11)$$

3. ANTENNA ELEMENT AND SUBARRAY CONFIGURATION

In this paper a uniform linear array(ULA) of 64 elements with a half-wavelength inter element spacing is considered. The antenna is divided into 8 regular sub arrays with each sub array of 8 elements. The configuration is explained in Table1.Since all sub arrays has the same number of elements, gain of all sub arrays are equal as shown in "Fig. 2". Here we have not applied any tapering, if we apply tapering, the gain of each sub array will be different because it will depend on the amplitude weights of each element. The phase centers of the sub arrays are calculated using equation (6) and shown in "Fig. 3".

Table1.Subarray and element configuration for regular subarrays

Element Index	*1-8*	*9-16*	*17-24*	*25-32*	*33-40*	*41-48*	*49-56*	*57-64*
Sub array Index	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*

In other configuration 8 irregular master sub arrays are formed by combining 2 regular sub arrays at digital level, as explained in table'2'

Table2.Subarray and element configuration for regular subarrays

Subarray Index	*1,3*	*2,5*	*4,8*	*6,7*	*9,11*	*10,13*	*12,16*	*14,15*
Master subarray Index	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*

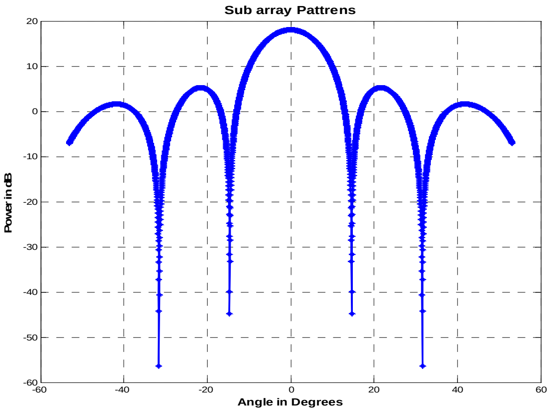

Fig. 2. *Regular Subarray pattrens*

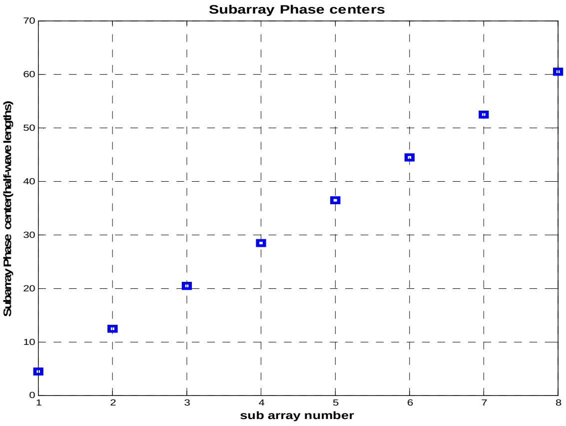

Fig. 3. *Regular Subarray phase centers*

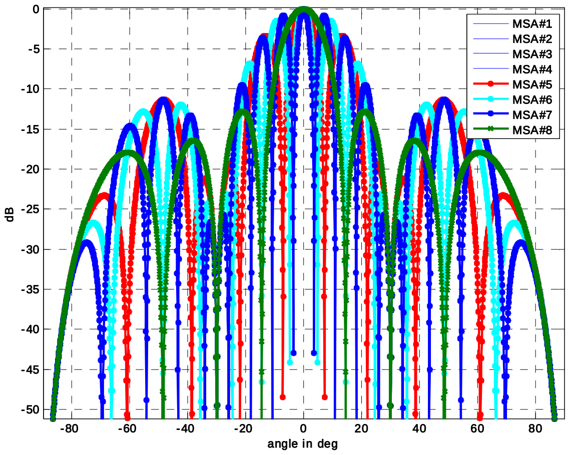

Fig. 4. *Irregular Subarray pattrens*

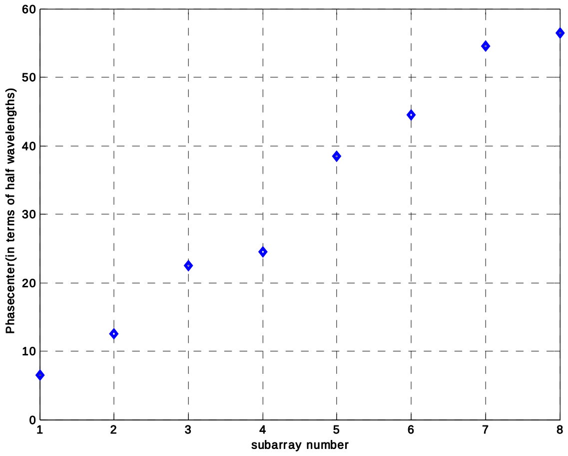

Fig. 5. *Iregular Subarray phase centers*

4. SIMULATION RESULTS

Here we assume two non coherent jammers are impinging on the array with a JNR of50 dB at element level from 48^0 and -15^0 . Bore-sight of the array is 0^0.The total number of i.i.d samples used for covariance matrix estimation is 300.The above two antenna configurations are used for adaptive beam forming.

Adaptive beamforing weights are estimated to maximize SNR in the look direction and minimize other directions.In case of Adaptive beam forming with regular sub array, we can notice there is a null even in the look direction because of the regular sub arrays as shown in the “Fig. 7”.This null is called as grating notch because of the periodicity of the regular sub array phase centers. Conventional beam forming is shown in “Fig. 6”,where there are no nulls in the jammer directions.

The periodicity of the regular sub arrays has been randomized and generated irregular sub arrays to minimize the grating notches as discussed in the above section, The adaptive beam forming with irregular sub arrays is shown in “Fig. 8”.It can be noticed that there are nulls in the directions of the jammers and grating notch is eliminated.

5. CONCLUSIONS

We have discussed the Adaptive beam forming method at sub array level to mitigate the interference effect on the radar performance. Adaptive beamformer places null in the look direction if the jammer is present at the grating lobe location of super array, We have discussed a method to convert the regular sub arrays into irregular sub arrays and eliminated the grating notches.

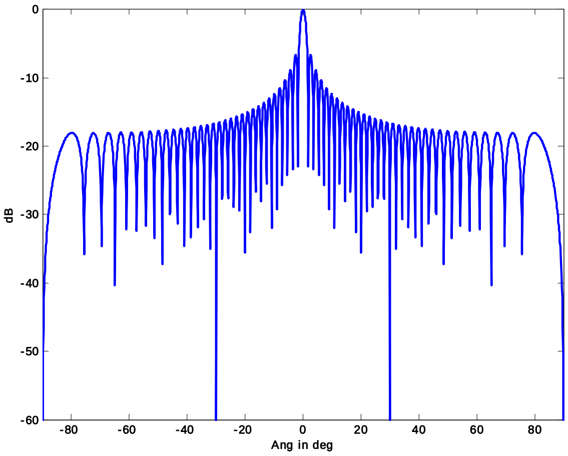

Fig. 6. Conventional beamforming with regular subarrays

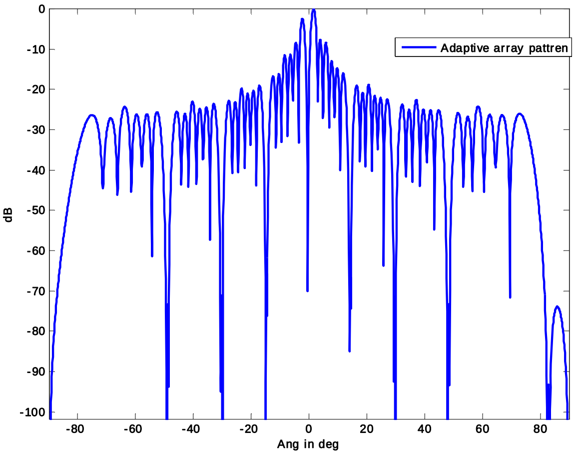

Fig. 7. Adaptive beamforming with regular subarrays

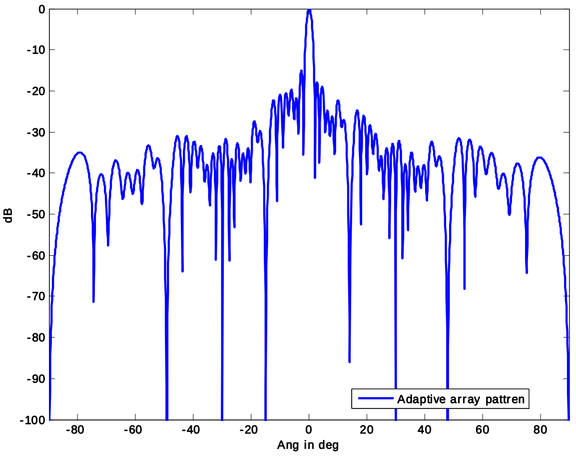

Fig. 8. Adaptive beamforming with irregular subarrays

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