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PERFORMANCE OF SMART ANTENNA SYSTEM WITH BEAMFORMING

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ABSTRACT

In this paper, beamforming is used to extract the time-domain signals coming from desired directions that are required to calculate the correlation coefficient with all directions of concern. We compare different beamforming methods.

Key Words- Smart antenna, beam forming & Electromagnetic waves

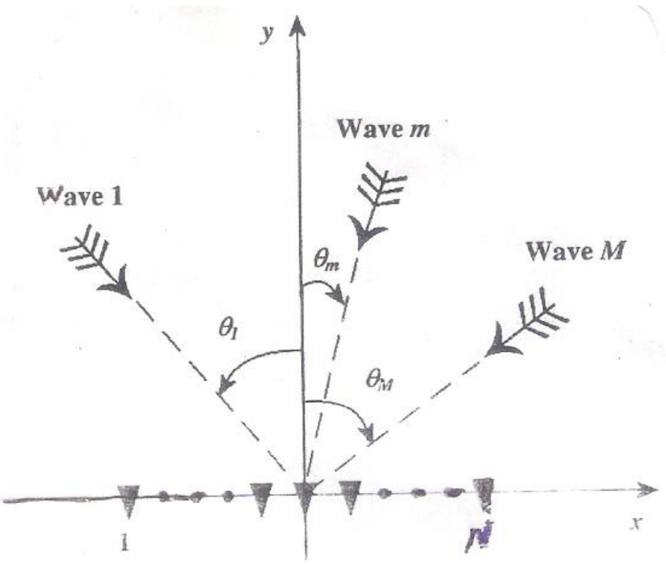
INTRODUCTION

The synthesis of beam patterns for antenna arrays is a determination of the desired excitation for each element to meet system requirements, such as beam width, side lobe level and directivity. This is possible on the premise that individual weights can be implemented and operated with absolute precision. However, the realistic weight circuits are inevitably susceptible to electrical and/or mechanical manufacturing errors, which result in a deviation of the designed pattern. *Hsiad and Roy* studied the relation between the maximum side lobe level and the random error by a statistical method, which is significant in radar system. The statistical method is a theoretical method to decide the tolerance from an acceptance pattern by modeling the distribution of a maximum side lobe level in a beam pattern, where errors are included and deriving the relation between the error and the array pattern. Therefore, Beamforming is a technique for controlling the directivity of the array. Its objective is to increase the gain in the direction of reception of the desired signals and tolerance the gain in all other directions. It is a form of spatial filtering.

THEORETICAL FORMULATION

Consider a uniform linear array composed by N elements with interelement spacing d is considered. M electromagnetic waves (which are supposed to be norrowband plane waves with central frequency ω) impinge on the array from directions θ_m, m= 1, …M as shown in figure-1

Fig.-1



The output of the ith element of the array x_i,

i = 1, ….., N, is expressed as

$$x_i = \sum_{m=1}^{M} S_m e^{-j(i-1)K_0 d \sin\theta_m} + n_i \qquad i = 1, \ldots, N \qquad \ldots(1)$$

Here $K_\theta = \omega\sqrt{\varepsilon_0 \mu_0}$ is the free space wave-number, S_m, m= 1, …, M is the output voltage of the first element of the antenna array assumed as reference, and n_i, i = 1, …., N is the output noise of the ith element of the array. In particular, a Gaussian noise with zero mean value and variance σ^2 is considered. Moreover, in order to be able to identify the M arrival directions, according to [5], we assume that M < N. Now we consider, $r = (r_{-n}, \ldots\ldots, r_0, \ldots\ldots, r_n)^T \in C^{2n+1}$ denote the autocorrelation of the beamformer weights, i.e.

$$r_m = \sum_{k=0}^{n-|m|} w_k \overline{w_{k+|m|}} \qquad \ldots(2)$$

Then the beam pattern $P(\phi)$ can be rewritten as

$$P(\phi) = \sum_{k=-n}^{n} r_m e^{-jm2\pi d \sin\phi/\lambda} \qquad \ldots(3)$$

For simplicity, we will focus on the standard case where d = λ/2.

Let

$$\upsilon(\theta) = \left(e^{-jn\theta}, \ldots, e^{-j\theta}, 1, e^{j\theta}, \ldots, e^{jn\theta}\right)^T \qquad \ldots(4)$$

And using the following variable change :

$$\theta := \Theta(\phi) = \pi \sin\phi \qquad \ldots(5)$$

$$\left[\tilde{a}_i, \tilde{b}_i\right] = \left[\Theta(a_i), \Theta(b_i)\right], \forall_i \qquad \ldots(6)$$

the beam pattern can be written as a trigonometric polynomial in θ. $P(\theta) = \upsilon^{H}(\theta) r,$

$$\theta \in [-\pi, \pi] \qquad \text{…(7)}$$

p_{i0}, p_{j0} be the ideally designed weight in amplitude and phase for i, j element, then the desired beam pattern ($AF_{desired}$) for this planar array can be expressed by

$$AF_{desired}(\theta, \phi) = \sum_{n=1}^{N} \sum_{m=1}^{M} P_{mno} e^{jk_0(m\mu d_x + n v d_y)} \qquad \text{…(8)}$$

Here μ= sinθ cos ϕ – sinθ_0 cos ϕ_0, v = sinθ sin ϕ – sinθ_0 cos ϕ_0 and d_x and d_y are the array element spacing in the x and y directions, respectively while d_x is the free-space wavenumber. Angles θ_0 and ϕ_0 are the beam pointing directions and θ and ϕ are the direction of the field point.

If there is a random amplitude/phase error $(\varepsilon = \delta e^{i\phi})$ in the weight (p_{i0} x ε_i, p_{j0} x ε_j), the beam pattern (AF_{error}) is deviated as shown in Fig.-2.

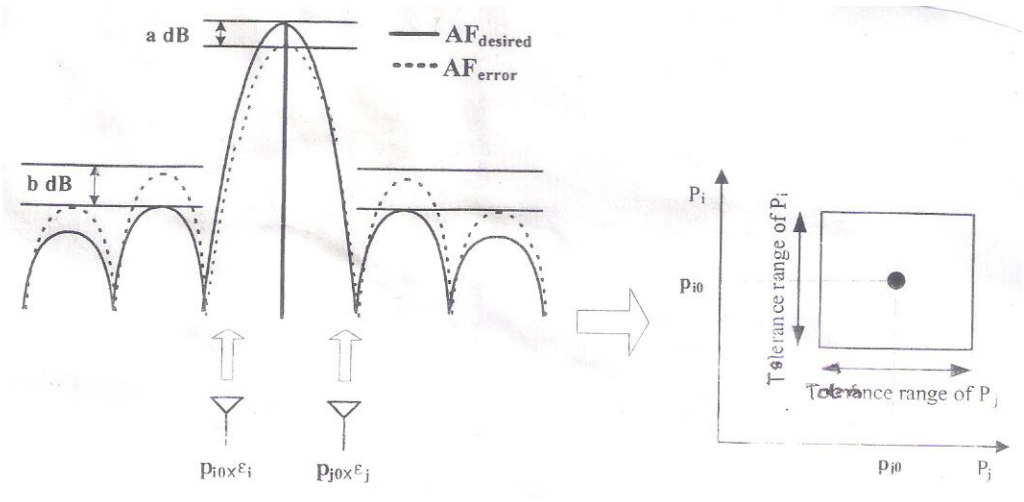


Fig.-2

For a linearly independent random error in amplitude and phase, the beam pattern can be described by

$$AF_{desired}(\theta,\phi)=\sum_{n=1}^{N}\sum_{m=1}^{M}P_{mno}\delta_{\min}e^{j\phi_{mn}}e^{jk_0\left(m\mu d_x+nvd_y\right)} \quad \ldots(9)$$

Here the δ_{mn} and ϕ_{mn} represent the error in amplitude and phase, respectively. The beamformer weight vector, w, is designed such that the signal coming from direction θ is captured, while the power of signals coming from all other directions is minimized. This is achieved by calculating w with respect to the constraint in equation (10)

$$\min\left\{w^H R_{yy} w\right\} \quad \ldots(10)$$

Subject to $\mathrm{Re}\left[a^H(\theta)w\right]=1$. This constrained minimization yields [4]

$$w=\frac{R_{yy}^{-1}a(\theta)}{a^H(\theta)R_{yy}^{-1}a(\theta)} \quad \ldots(11)$$

In practice, w relies on the sample covariance matrix of R_{yy} and the θ direction. The time-domain signal propagating in this direction is then denoted by

$$Y(t)=\sum_{i=1}^{M}w_i^* y_i(t)=w^H y(t) \quad \ldots(12)$$

Equation (12) is the time-series output of the Minimum Variance Distortionless Response (MVDR) beamformer for the path in direction θ. Y(t) can be used to estimate the correlation coefficient. Note that in order to effectively extract Y(t) for a path at a particular direction from coherent multipath signals, the correlation matrix, R_{yy}, in Equation (11) is spatially smoothed. A matrix, A_k of size M x (D–1), that contains all wavefronts except $a(\theta_k)$, is formed by removing the mode vector $a(\theta_k)$ due to the signal propagating from direction θ_k from the M x D matrix A. Assume W_k is the M x M orthogonal projection matrix of A_k [5], i.e.

$$W_k = I - A_k\left(A_k^H A_k\right)^{-1} A_k^H \quad \text{...(13)}$$

Here I is the M x M unit matrix. The time-domain signal propagating in the direction of θ_k is then found from

$$Y_k(t) = [W_k a(\theta_k)]^H W_k\, y(t) \quad \text{...(14)}$$

Clearly, $Y_k(t)$ is used to estimate the correlation coefficients related to the path in direction θ_k. If the correct time delay is chosen, a signal propagating in the desired direction will be reinforced and noise will be suppressed.

If τ_m is the time delay to be added to the mth antenna to steer in a particular direction θ, the beam-formed signal Y(t) can be written as

$$Y(t) = \sum_{m=0}^{M-1} w_m y_m(t - \tau_m) \quad \text{...(15)}$$

The time series Y(t) thus obtained can be used to estimate the corresponding correlation coefficient. The least-squares estimate of G is

$$G = AA_e^H\left(A_e A_e^H\right)^{-1} \quad \text{...(16)}$$

The calibrated antenna output vector is then

$$Y = Gx \quad \text{...(17)}$$

This antenna output is then used in all of the algorithms.

Results and discussion

The goal for error tolerance is to specify the smallest value that will allow 95% of the randomly excited arrays to produce acceptable beam patterns. This is turn defines the maximum tolerance region. The maximum error tolerance for each element is defined as the maximum boundary of tolerance region where an elements error within that region shows an acceptable beam pattern. As shown in Fig.-2, that a 3^0 detection angle error occurs when the 5^{th} element has an amplitude error but all the others are free of error. The magnitudes and phases of the symmetric weights are given in fig.-3.

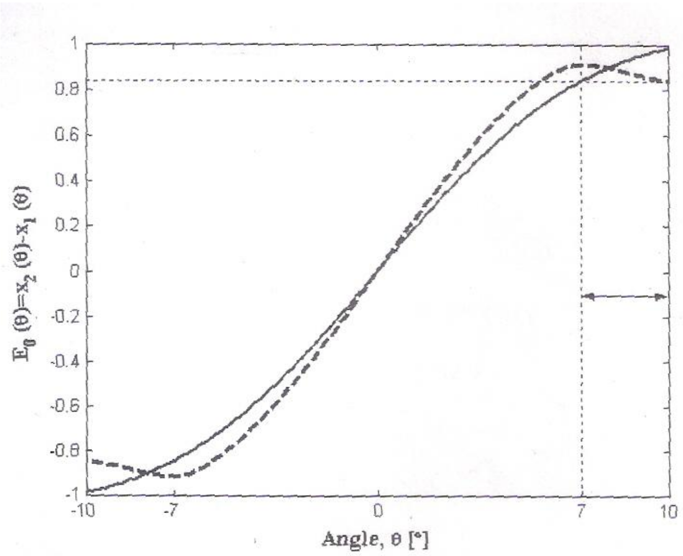


Fig.-3

This confirms our theoretical result that all perturbed array weights within the given error band produce array patterns that fit in the original mask. We estimated also the incident angles and correlation coefficients for different beamforming algorithms. minimum variance beamforming adaptive beamforming and delay and sum beam forming. The probability of correctly deciding that the two paths are indeed from distinct sources is plotted again the threshold values in figure-4, the paths were incident from` -30^0 and 20^0.

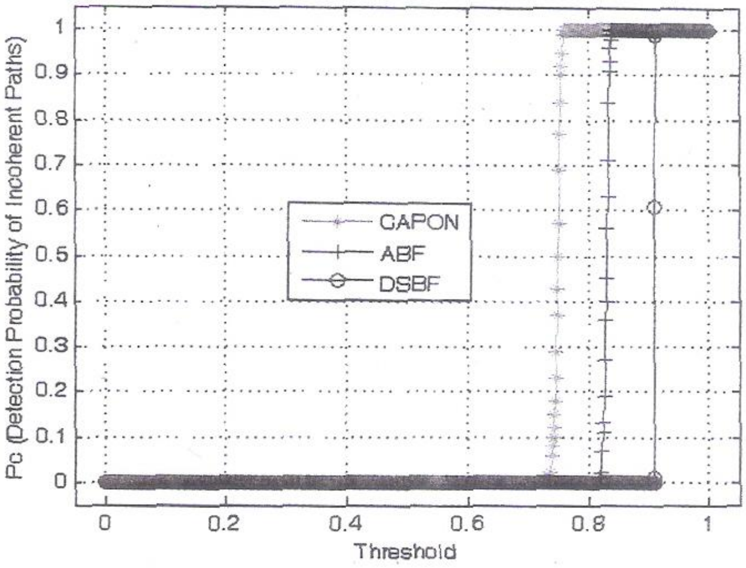


Fig.-4

In above figure represent the detection probability of incoherent paths and minimum variance beamforming gave the best performance.

CONCLUSION

In this paper, we have shown that the maximum tolerance region for each element is determined proportional to the its weight on beam pattern. This technique will be beneficial to the analysis of communication arrays such as smart antennas and satellite communication antennas also.

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