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ADAPTIVE BEAMFORMING AND CANCELLATION OF JAMMER USING LINEAR ARRAY ANTENNA SYSTEM

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ABSTRACT

The radiation pattern of an antenna depends on the type, size and parameters of feed current. To change the direction of maximum and minimum gain the mechanical steering is necessary. Electronic steering is only possible in array antenna system with adaptive feed current system. Relative magnitude of feed currents, relative phases or separation between antenna elements, geometric shape of the array are responsible for the overall radiation pattern. Another popular technique of analysis of antenna parameters using Rao-Wilton-Glisson (RWG) edge elements consists of pair of dipole of triangular shape. In this paper we will observe the impact of antenna parameters on the shape of radiation pattern of both linear and rectangular array using the concept of conventional antenna engineering and RWG approach.
Key words: RWG elements, array factor, broadside and endfire array, Reference Antenna and MoM.

INTRODUCTION

In both mobile cellular and satellite communication, channel capacity could be extended using space division multiplexing (SDMA) on the existing access techniques like TDMA, FDMA or CDMA. Array antenna plays important role for SDMA technique to repeat the logical channel twice or more. Although single element antenna is prevalent now-a-days in both fixed and mobile communications but to get high directivity, narrow beams, low side lobe, steer able beams, particular patterns characteristics etc. commonly a group of antenna elements, called array antenna, or simply array is used. One of the major problems of wireless communication specially mobile cellular communication is co-channel interference, limits the carried traffic of network. To combat this interference dynamic cell formation in the direction of desired signal, at the same time reduction of radiation lobe in the direction of interference is necessary. Array antenna system has the ability to provide dynamic radiation pattern summarized in [1]-[6]. The radiation from individual elements will combine, resulting in reinforcement in some directions and cancellation in others to give greater gain and better directional characteristics which is impossible using individual antenna [7]-[11]. It could be used in various configurations for both mobile and satellite communications to provide Space Division

Multiplexing (SDMA) specially base station of mobile cellular network or LEO satellite system to increase number of users within limited spectrum.

In array antenna several antennas are connected and arranged in a regular structure (linear, planer, circular) to form a single antenna. Antenna array produces radiation pattern, actually the combination of pattern of single elemental antenna. Single antenna elements are very popular but they are fixed for particular feed current and band of frequency. There are five factors which control the overall pattern of array antenna. They are:

a. The geometrical configuration of the overall array (linear, circular, rectangular,spherical etc.)
b. The relative displacement between the elements
c. The excitation amplitude of the individual elements
d. The excitation phase of the individual elements
e. The relative pattern of the individual elements

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Depending on relative phase, amplitude and separation among the antenna elements we can get beam of desired directivity and direction. Fig.1 shows the basic structure of a linear array antenna system.

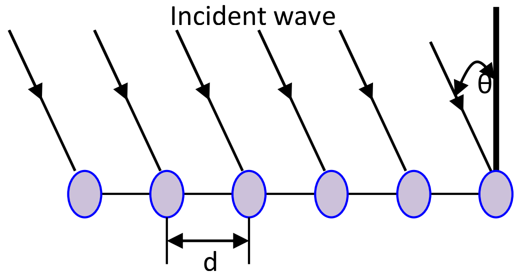

Fig 1: Linear array antenna

Our desired signal often contaminated by unwanted signal. Normally we use filters to solve this problem. Conventional filters often cannot solve the situation because we do not know the nature of input signal. At that time we need adaptive filters which can change its characteristics dynamically. Adaptive filters are such filters which can change its characteristic according to the input signal. It has digital filter with adjustable coefficients and an adaptive algorithm. To estimate the desired output, it first estimates an error then subtracts it from the received signal. The output is then used as feedback to the algorithm to update the filters coefficients.

Distribution of surface current on the body of an antenna and profile of magnetic field intensity/ current density is considered the most important parameter in selection of antenna in receiving mode. In receiving mode electric field produces a distributed current on the antenna's surface which in turn creates a voltage difference across the feed points of antenna. This gap voltage constitutes the received signal. From the energy transfer viewpoint, an antenna in the receiving mode collects electromagnetic wave energy over a certain area [22-24].

The most important antenna parameter is its surface current distribution during reception of any signal. The most convenient method of analysis of such surface current distribution is 'Method of Moments' (MoM) based on the RWG basis functions summarized in [25-29]. In this paper we determine the two and three dimensional radiation pattern of linear and rectangular array antenna using RWG and MoM.

In most occasions we need to transmit or accept signal from particular direction. For this purpose we have to use adaptive beamforming technique. Adaptive beamforming is a special technique by which we can transmit or receive signal from any desired direction while denying the signal of same frequency from other directions. Such behaviors are found for relative phase, amplitude and separation among the antenna elements, but the adaptive filter do the same job by multiplying an weighting factor to a feed line like fig.2 explained explicitly in [11]-[13].

In communication field unwanted signal is a great problem. So we try to achieve our desired signal without unwanted noise. Jamming signal means a signal that introduces interference into a communication channel. The main objective of our project is to protect jamming signal which may come from any direction; on that direction we will tune the gain of antenna. Antenna gain is enhanced in the direction of arrival of desired signal and reduced in the direction of interference.

The objective of the paper is: simulation of radiation pattern of linear array using the concept of rwg element and observation of change of main lobe from broadside to endfire with change in progressive phase, simulation of 2D and

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3D radiation pattern of rectangular array antenna system, sidelobe cancellation using reference antennas and protection of jamming from several directions.

SYSTEM MODEL

Array antenna system

In array antenna system antenna elements are placed in different geometric shape for example linear, circular, rectangular array etc. Radiation pattern of an array antenna system is governed by the array factor i.e. radiation pattern of single element of the multiplied by the array factor provided the combined radiation pattern. For a linear array the array factor is expressed as:

$$AF = 1 + e^{j(kd\cos\theta+\beta)} + e^{j2(kd\cos\theta+\beta)} + \ldots \quad \ldots \quad \ldots + e^{j(N-1)(kd\cos\theta+\beta)} \tag{1}$$

Where d is separation between antenna elements, $k = 2\pi d/\lambda$, $\lambda$is the wavelength is the progressive phase and θ is the angle between array axis and the link between Tx and Rx. The AF is written in a convenient form like:

$$AF = \sum_{n=1}^{N} e^{j(n-1)\Psi} = \frac{e^{jn\Psi}-1}{e^{j\Psi}-1} = \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)}; \text{ where } \Psi = kd\cos\theta + \beta \tag{2}$$

The nulls of the array are found at:

$$AF = \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)} = 0 \Rightarrow \sin\left(\frac{N\psi}{2}\right) = 0 \Rightarrow \frac{N\psi}{2} = \pm n\pi \Rightarrow \theta_{null} = \cos^{-1}\left\{\frac{\lambda}{2\pi d}\left(-\beta \pm \frac{2n}{N}\pi\right)\right\} \tag{3}$$

Similarly for maxima of array:

$$\Rightarrow \sin\left(\frac{\psi}{2}\right) = 0 \Rightarrow \frac{\psi}{2} = \pm m\pi \Rightarrow \theta_{\max ima} = \cos^{-1}\left\{\frac{\lambda}{2\pi d}(-\beta \pm 2m\pi)\right\} \tag{4}$$

For broadside and endfire array the progressive phase $\beta = 0$ and $\pm kd$ respectively.
To control the null and maxima the excitation coefficients of the array is selected by Bionomial array or Dolph-Tschebyscheff array.

RWG Elements

The source of an antenna metal is divided into separate triangles where each pair of triangles T_m^+ and T_m^- (both pair) share common edge l_m having areas A_m^+ and A_m^-. Each pair of such triangle is called RWG edge elements [10, 16]. Fig.1 shows the RWG elements of a thin dipole of antenna.

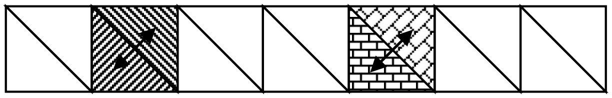

Fig.2 RWG edge elements of a thin dipole antenna

Now the moment equation **Z.I = V**, where **Z** is an M x M impedance matrix and **V** is the voltage vector with dimension M x 1 and $\mathbf{I} = [I_1, I_2, I_3, \cdots, I_M]^T$, is the $M \times 1$ current coefficient vector, where T represents transpose.

Now, the surface current diversity J_K for a given triangle k is obtained as

$$J_K = \sum_{m=1}^{M} I_m f_m(r) \tag{5}$$

where r is in triangle T_k and the basis function $f_m(r)$ is expressed as:

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$$f_m(r) = \begin{cases} \frac{l_m}{2A_m^+} \rho_m^+(r)\,;\, r \text{ in } T_m^+ \\ \frac{l_m}{2A_m^-} \rho_m^-(r);\, r \text{ in } T_m^- \\ 0; \quad \text{Otherwise} \end{cases} \tag{6}$$

Adaptive Beamforming

Adaptive beamforming is an adaptive technique by which we can transmit or detect the desired signal from the direction of arrival of signal. Signal may come from any direction but we have to tune the antenna to extract the target signal at the same time the interference from other direction has to be eliminated. Principal component of an adaptive beam former is an adaptive filter consists of two parts, a digital filter with adjustable coefficients and adaptive algorithm which is used to adjust the coefficients of the filter

Sidelobe Cancellation with Two Reference Antennas

In some practical situation multiple jammers can present. To match with multiple jammers at the same time, it is necessary to have more than one reference omni. Considering two spatially separated reference omnis, the error signal is formed by subtracting both reference output from the primary signal like fig.3.

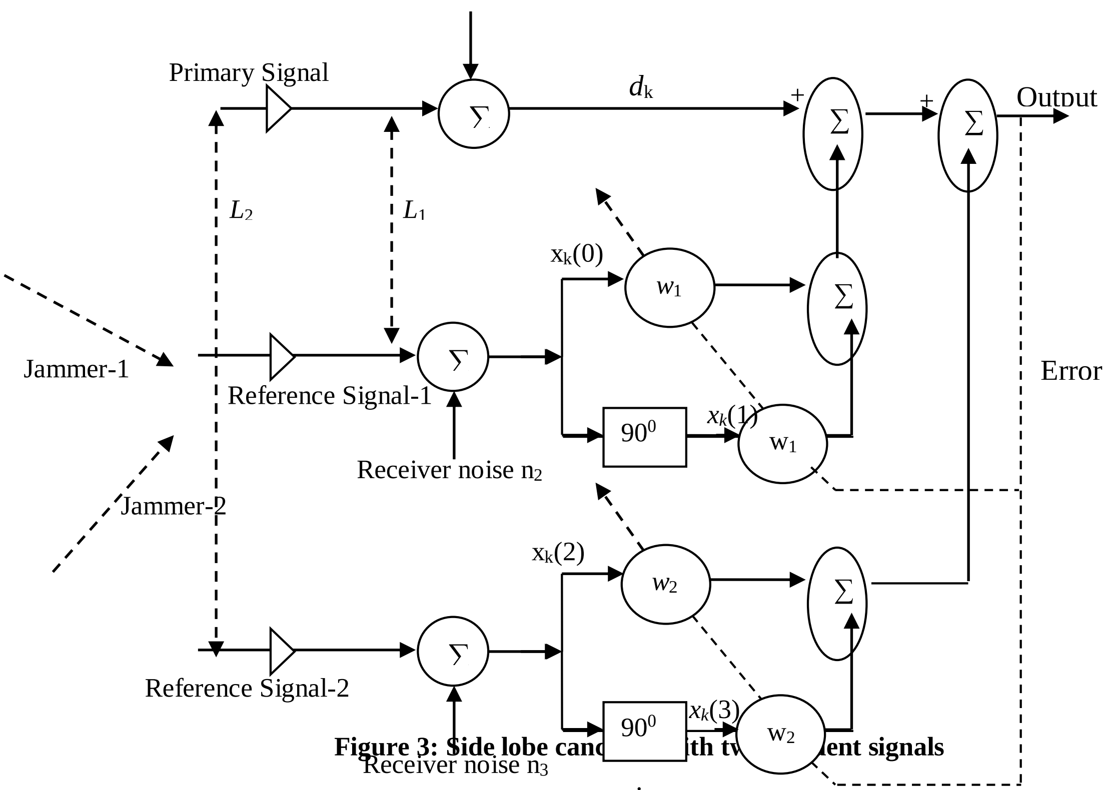

Figure 3: Side lobe canc ith tw ent signals

Here the primary signal is $c\cos k\omega_0$, the signal of reference: 1 is $c\cos[(k+\delta_{10})\omega_0]$ and the signal of reference: 2 is $c\cos[(k+\delta_{20})\omega_0]$.

On the other hand, $\delta_{10}^{'} = kl_1 \sin\theta_0$, $\delta_{10} = \frac{\delta_1^{'}}{\omega}$, $\delta_{20}^{'} = kl_2 \sin\theta_0$ and $\delta_{20} = \frac{\delta_2^{'}}{\omega}$.

Where $k = \frac{2\pi}{\lambda}$ and θ_0 is the direction of arrival of signal.

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The desired signal,

$$d_k = c\cos k\omega_0 + n_1 + j_1 + j_2 \tag{7}$$

The cross correlation vector,

$$\mathbf{P} = E\begin{bmatrix} d_k x_{k(0)} \\ d_k x_{k(1)} \\ d_k x_{k(2)} \\ d_k x_{k(3)} \end{bmatrix} \tag{8}$$

Here

$$x_{k(0)} = c\cos[(k+\delta_{10})\omega_0] + n_2 + j_1 + j_2$$
$$x_{k(1)} = c\sin[(k+\delta_{10})\omega_0] + n_2' + j_1' + j_2'$$
$$x_{k(2)} = c\cos[(k+\delta_{20})\omega_0] + n_3 + j_1 + j_2$$
$$x_{k(3)} = c\sin[(k+\delta_{20})\omega_0] + n_3' + j_1' + j_2'$$

$$\mathbf{P} = \begin{bmatrix} \sigma_s^2\cos(\delta_{10}\omega_0) + \sigma_{j1}^2 + \sigma_{j2}^2 \\ \sigma_s^2\sin(\delta_{10}\omega_0) \\ \sigma_s^2\cos(\delta_{20}\omega_0) + \sigma_{j1}^2 + \sigma_{j2}^2 \\ \sigma_s^2\sin(\delta_{20}\omega_0) \end{bmatrix}; \; where\ \sigma_s^2 = \frac{c^2}{2} \tag{9}$$

The autocorrelation matrix,

$$R = E[X_k X_k^T]$$

$$= \begin{bmatrix} \sigma_s^2+\sigma_n^2+\sigma_{j1}^2+\sigma_{j2}^2 & 0 & \frac{c^2}{2}\cos(\delta_{10}-\delta_{20})\omega_0+\sigma_{j1}^2+\sigma_{j2}^2 & \frac{c^2}{2}\sin(\delta_{20}-\delta_{10})\omega_0 \\ 0 & \sigma_s^2+\sigma_n^2+\sigma_{j1}^2+\sigma_{j2}^2 & \frac{c^2}{2}\sin(\delta_{10}-\delta_{20})\omega_0 & \frac{c^2}{2}\cos(\delta_{10}-\delta_{20})\omega_0+\sigma_{j1}^2+\sigma_{j2}^2 \\ \frac{c^2}{2}\cos(\delta_{20}-\delta_{10})\omega_0+\sigma_{j1}^2+\sigma_{j2}^2 & \frac{c^2}{2}\sin(\delta_{10}-\delta_{20})\omega_0 & \sigma_s^2+\sigma_n^2+\sigma_{j1}^2+\sigma_{j2}^2 & \frac{c^2}{2}\sin(\delta_{20}-\delta_{10})\omega_0 \\ \frac{c^2}{2}\sin(\delta_{20}-\delta_{10})\omega_0 & \frac{c^2}{2}\cos(\delta_{20}-\delta_{10})\omega_0 & 0 & \sigma_s^2+\sigma_n^2+\sigma_{j1}^2+\sigma_{j2}^2 \end{bmatrix} \tag{10}$$

Now the optimum weighting factor can be determined from Winner filter theory.

$\therefore$ The output signal,

$$= \cos k\omega_0 - w_{11}(\cos k\omega_0\cos\delta_1\omega_0 - \sin k\omega_0\sin\delta_1\omega_0) - w_{12}(\sin k\omega_0\cos\delta_1\omega_0 + \cos k\omega_0\sin\delta_1\omega_0)$$
$$- w_{21}(\cos k\omega_0\cos\delta_2\omega_0 - \sin k\omega_0\sin\delta_2\omega_0) - w_{22}(\sin k\omega_0\cos\delta_2\omega_0 + \cos k\omega_0\sin\delta_2\omega_0)$$
$$= A\cos(k\omega_0 - \alpha)$$
$$= \cos k\omega_0(1 - w_{11}\cos\delta_1\omega_0 - w_{12}\sin\delta_1\omega_0 - w_{21}\cos\delta_2\omega_0 - w_{22}\sin\delta_2\omega_0) + \sin k\omega_0(w_{11}\sin\delta_1\omega_0$$
$$- w_{12}\cos\delta_1\omega_0 + w_{21}\sin\delta_2\omega_0 - w_{22}\cos\delta_2\omega_0)$$
$$= \cos k\omega_0 A\cos\alpha + \sin k\omega_0 A\sin\alpha \tag{11}$$

∴ The array gain,

$$A^2 = (1 - w_{11}\cos\delta_1\omega_0 - w_{12}\sin\delta_1\omega_0 - w_{21}\cos\delta_2\omega_0 - w_{22}\sin\delta_2\omega_0)^2 + (w_{11}\sin\delta_1\omega_0 - w_{12}\cos\delta_1\omega_0 + w_{21}\sin\delta_2\omega_0 - w_{22}\cos\delta_2\omega_0)^2 \quad (12)$$

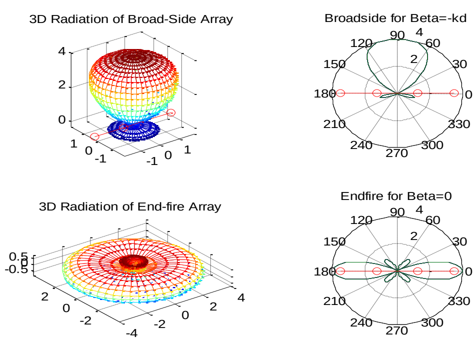
Array gain in generalized form:

$$A(\theta) = \sqrt{\left[1 - \sum_{i=0}^{m}\left[W_{i,1}\cdot\cos\left(\beta\cdot L_1\cdot\sin(\theta)\right) + W_{i,2}\cdot\sin\left(\beta\cdot L_1\cdot\sin(\theta)\right)\right]\right]^2 + \left[\sum_{i=0}^{m}\left[W_{i,1}\cdot\sin\left(\beta\cdot L_1\cdot\sin(\theta)\right) - W_{i,2}\cdot\cos\left(\beta\cdot L_1\cdot\sin(\theta)\right)\right]\right]^2} \quad (13)$$

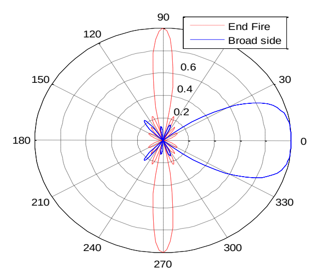
Where, m is the number of elements of beamformer, β is the phase constant, L_i is the separation of elements of beamformer and $W_{i,j}$ is the waiting factor; i = 0, 1, 2, …. , m; j = 1 and 2.

RESULT

Let us first observe the impact of relative phase angle in creation of radiation pattern in a linear array antenna system. If the radiation of main beam is directed along the axis of the array in called endfire array again if the axis of the beam is perpendicular to the direction of axis of the array called broadside antenna array. The radiation pattern of both type of array is shown in fig.4.



(b) 3D and 2D Radiation pattern



(b) Radiation pattern in polar co-ordinate

Fig.4 3D and 3D radiation pattern of linear array antenna system for the case of endfire and broadside

The change in orientation of radiation pattern from endfire to broadside with relative phase shift is shown in fig.5 for number of antenna element N = 2, 4, 8 of a linear array.

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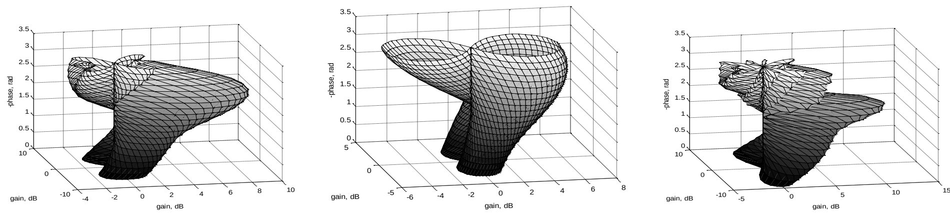
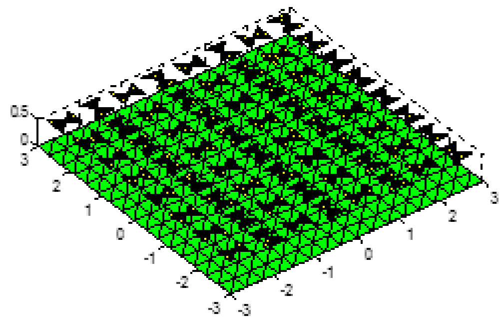
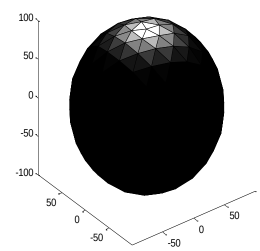
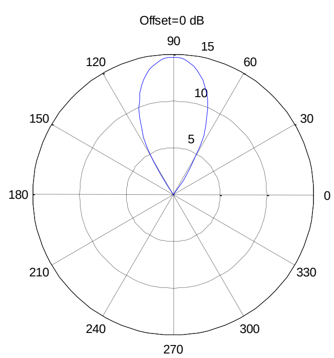


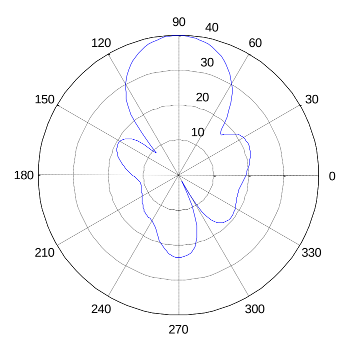
(a) *N*=2 (b) *N*=4 (c) *N*=8

Fig. 5(a) shows the top view of distribution of rwg elements of rectangular array antenna system consist of bow tie dipole where the size of the array is 8×8. The work is done in MATLAB 9.0 on a machine with core i5 processor. The size of the ground plane is 6×6cm, the size of antenna element 0.45×0.45cm with the flare angle of 90^0. Three and two dimensional radiation pattern of the arrays is shown in fig.6(b) and (c) (x-z plane)









(a) 8×8 array **(b) 8×8 array Balanis' relative power10log10(U/max(U))**

Fig. 6 Three and two dimensional radiation pattern

Now we will observe how appropriate gain provided to desired direction and null or jammer in the direction of interference is placed using adaptive beamforming of section 2. To get few nulls only one reference antenna is enough but of more nulls, two reference antenna system is used. Radiation pattern of two reference adaptive beamforming is shown in Fig 7 to Fig 8. Input of weighting factors is visualized form the Fig. For fig. 9 when $w11 = -0.48, w12 = -0.87, w21 = 1.7, w22 = 1$ the null forms along $30°$ and $150°$; $60°$ and $120°$. When $w11 \approx w12 \approx w21 \approx -w22$ the nulls form only on $0°$ and $180°$. But if the $w11 = 0.25, w12 = 0.5, w21 = -0.15, w22 = -0.5$ the nulls form along $225°$ and $315°$.

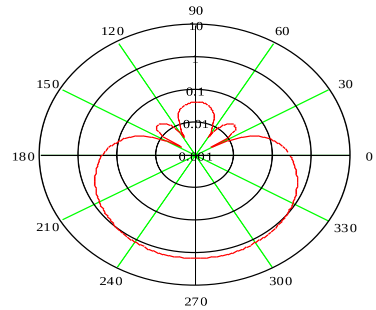


Fig.7. Radiation Pattern of two reference antenna system (w11=-0.48, w12=-0.87, w21=1.7, w22=1)

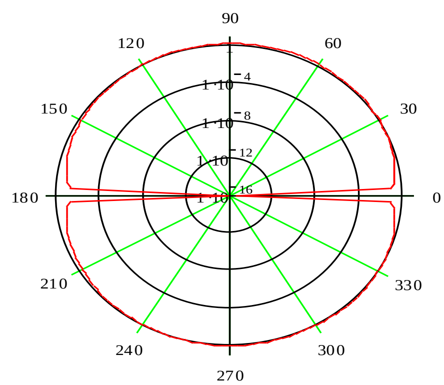


Fig.8. Radiation Pattern of two reference antenna system (w11=0.5, w12=0.5, w21=0.5, w22=-0.5)

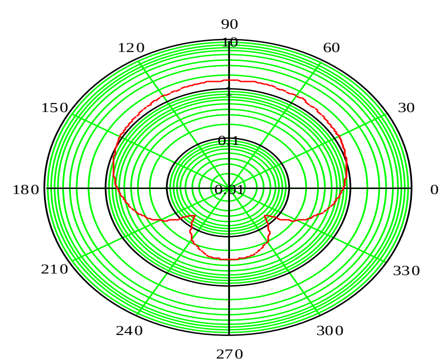


Fig.9. Radiation Pattern of two reference antenna system (w_{11} = 0.25, w_{12} = 0.5,w_{21} = -0.15, w_{22} = -0.5)

CONCLUSIONS

In this project work two elements array antenna is used to control jamming signals from four directions whereas the single element antenna does the same job for two directions. The adaptive array tunes the antenna gain in such a way that the system can decrease the antenna gain on the direction of jammers and increase the gain in the direction of arrival of required signal. Increasing of antenna element will give the better performance but at the expense of mathematical complexity. Basic wiener filter theory is applied in this project work; whereas incorporation of least mean square (LMS), recursive least square (RLS) and Kalman algorithm can be used to observe the performance of the system.

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