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Analysis and Design of Distribution of Element Spacing of Micro strip Reflect Array Antenna

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ABSTRACT: Reflect array antenna consisting of micro strip rectangular patches with average size of half wavelength on a thin FR4 dielectric substrate over a ground plane is described. The actual shape and spacing of the elements are designed depending on the feed horn pattern to produce phase pattern for pencil beam in a desired direction. Different spacing between the patch elements are considered for formation of plane wave front for pencil beam. MATLAB codes are developed for determining the induced surface currents on the patches due to incident radiation from the feed horn. Spherical to rectangular Co-ordinate transformations are automatically generated from the code and radiation pattern of the array is determined. Two basic inter-element spacings are considered, uniform spacing, and spacing with arith matic progression for optimum performance of 11x11 elements and 51x51 elements. . It is observed that AP spacing with decrement by λ/16 gives better result compared to uniform spacing.An experimental investigation has been carried out on array of 51x51 elements and found agreement with theoretical results.

KEYWORDS: Reflectarray, Microstrip antenna.

I. INTRODUCTION

The schematic diagram of reflectarray antenna is shown in Fig. 1, which comprised of printed elements on a substrate of thickness h and relative permittivity and fed by a pyramidal horn antenna located at the virtual focal point F.

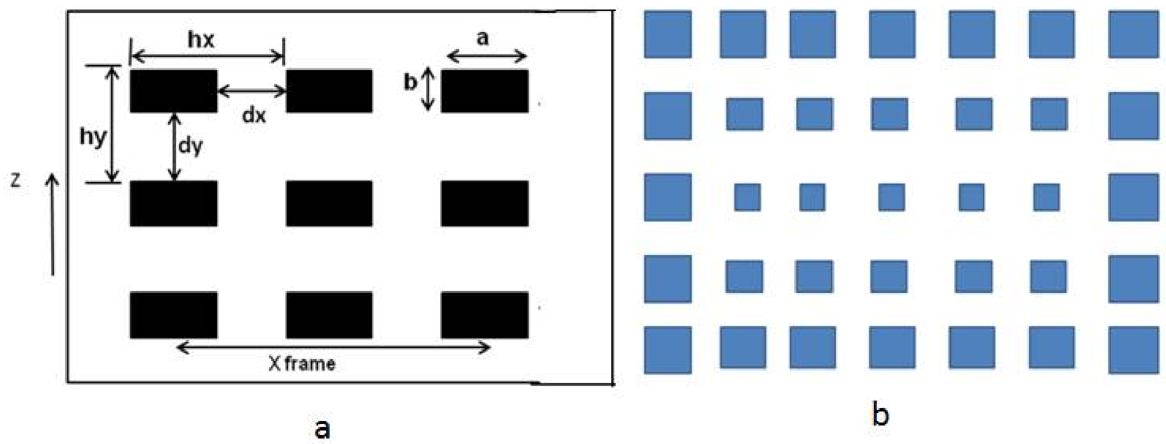

Fig. 1. Centre-fed reflect array(a. Uniform spacing b. Non uniform spacing

Patch dimension are adjusted to realize an equiphase aperture field distribution to produce broadside radiation from the reflectarray. This can be achieved when the following phase relationship of the incoming spherical field of horn is satisfied [1]:

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$$k_0(FA - FO) - \phi_A = 2n\pi \tag{1}$$

where n is an integer representing the n th element at A where the first element is located at the origin O, k_0 is the free space wavenumber, and ϕ_A is the scattered phase generated by the patch located at point A. Right hand side of Eqn. (1) represents a phase difference of $2\pi n$ between nth patch and the patch 1 located at O, which is the center of reflectarray.

For a scanned beam OB as shown in Fig.2, the phase relation

$$k_0(FA - F\vec{O} \cdot O\vec{B}) - \phi_A = 2n\pi \tag{2}$$

must be satisfied.

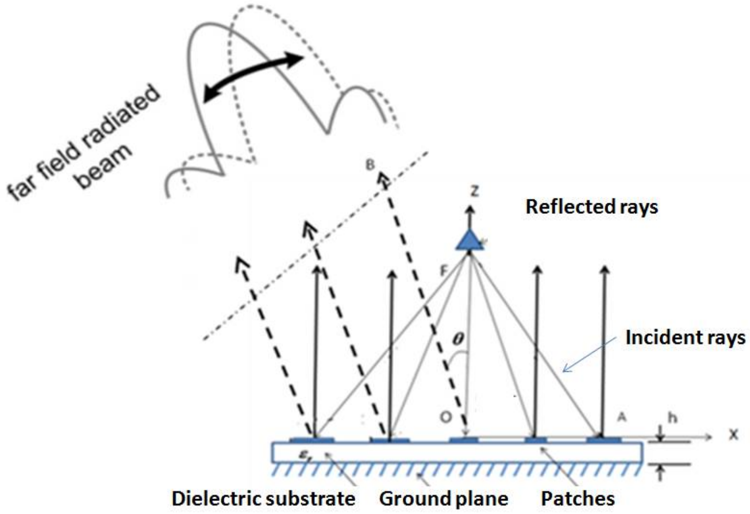

Fig.2 A scanned beam reflect array

Lattice dimensions along the x-axis and y-axis, dx and dy, respectively are selected to be less than free-space half wavelength $\lambda_0/2$ to prevent grating lobes. A general 2-D array is shown in Fig.3. The performances of reflect array are derived from the general array theory while the excitation current on the elements is obtained from the induced current on the patches due to primary feed radiation from the virtual focus F. The pencil beam similar to paraboloid reflector is generated when the phase relationship satisfies the Eqns.1-2.

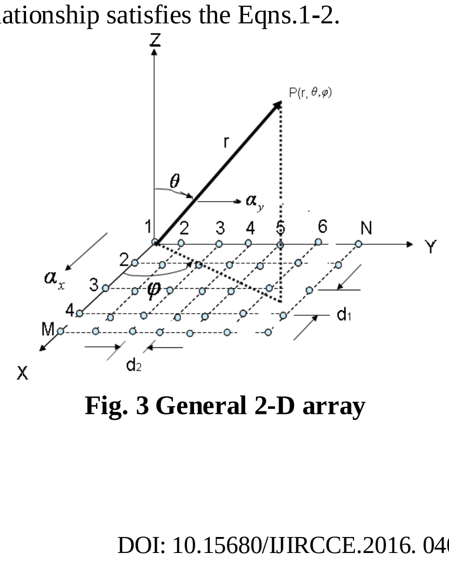

Fig. 3 General 2-D array

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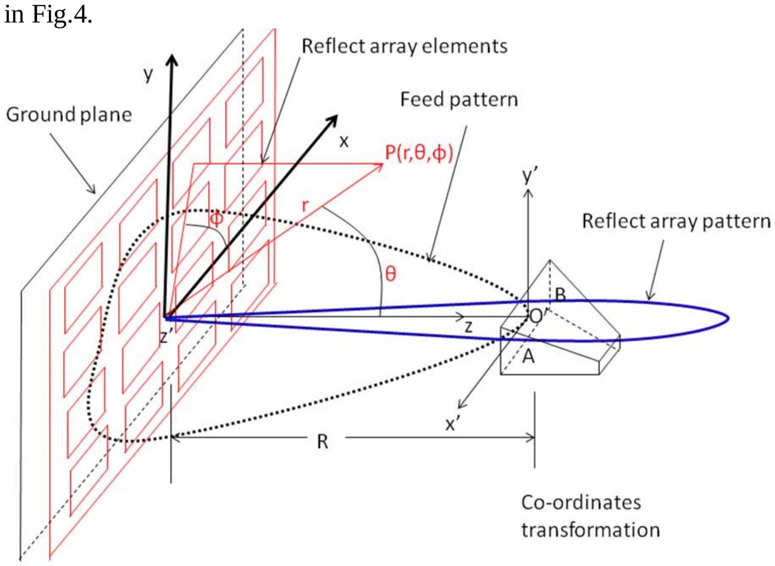
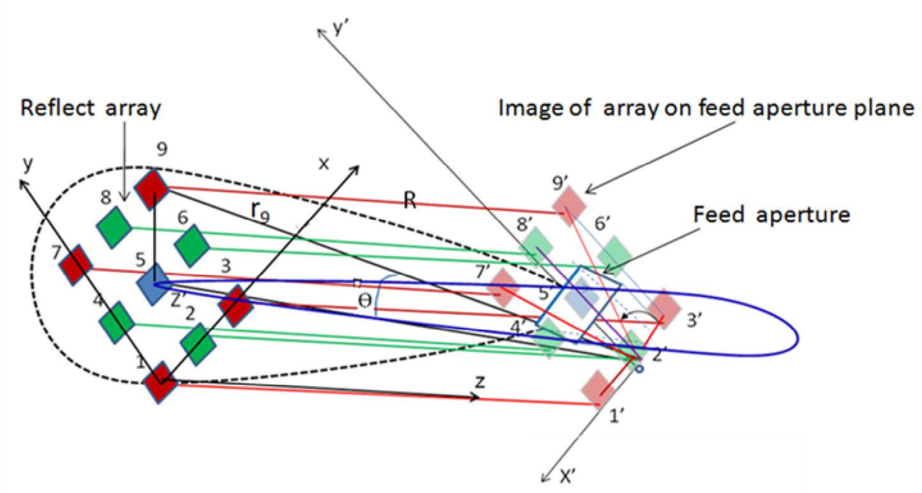
II. THEORETICAL ANALYSIS

In this paper, first a uniform array with 11x11 and 51x51 square patch elements are designed where each of the elements are taken of equal size of dimension λ/2. The patches are equidistant from each other. Distance of the patches from center to center is represented by hx and hy according to x axis and y axis, respectively. The feed horn antenna is placed in front of the center of the reflector plate.

Secondly, a non uniform array of equal square size elements with spacing according to Arithmetic Progression is taken to optimize the performance to yield broad side radiation with high gain. The geometrical representation of the array with feed is shown in Fig.4.



(a)



$\Theta1 = \Theta3 = \Theta7 = \Theta9 \qquad \Theta2 = \Theta4 = \Theta6 = \Theta8, \Theta5 = 0^0$

$\phi1 = 180^0 - \phi3 = 180^0, \phi4 = 180^0 - \phi6 = 180^0 - 45^0 = 135^0,$

$\phi7 = 180^0 - \phi9 = 180^0 - 63^0 = 117^0, \ \phi2 = 0^0, \phi3 = 0^0, \phi5 = \phi8 = 90^0$

(b)

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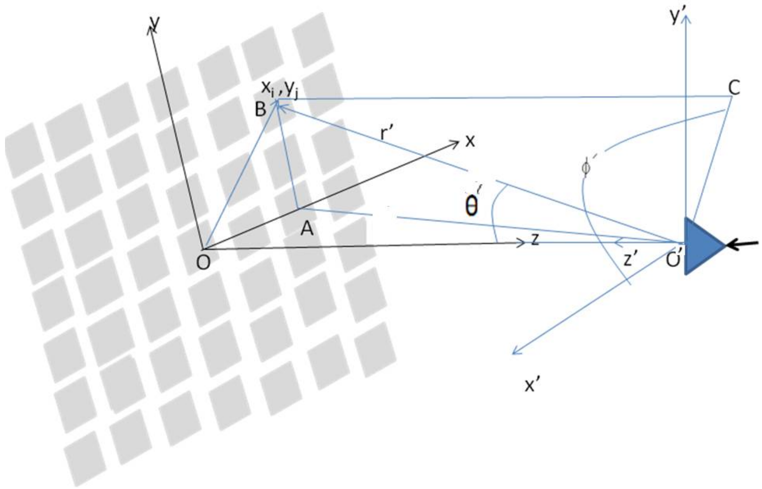

(c)

Fig.4 The geometrical representation of the array with feed

Determination of coordinates of large number of array elements

The steps of analysis are the following where MATLAB is extensively used for all these computations:

- Determination of magnetic field radiation of horn at array elements in source co-ordinates.
- Transformation of source co-ordinates into array co-ordinates and determination of induced current on the array elements.
- Determination of antenna array factor from the induced current on the array elements.

Characterization of feed for Reflect Array Elements:

The reflect array elements are excited by the radiation pattern of a pyramidal horn antenna. To determine the aperture field components for dominant TE 10 mode and radiation pattern, a detail of dimensions of a typical pyramidal horn is required as shown in Fig.5.

The aperture field components are given by

$$E_y'(x', y') \cong E_0 \cdot \cos\left(\frac{\pi}{A} x'\right) \cdot e^{-j\left(\frac{kx'^2}{2\rho_{0h}} + \frac{ky'^2}{2\rho_{0e}}\right)} \quad \text{---- (3)}$$

$$H_x'(x', y') \cong \frac{-E_y'(x', y')}{\eta} \quad \text{---- (4)}$$

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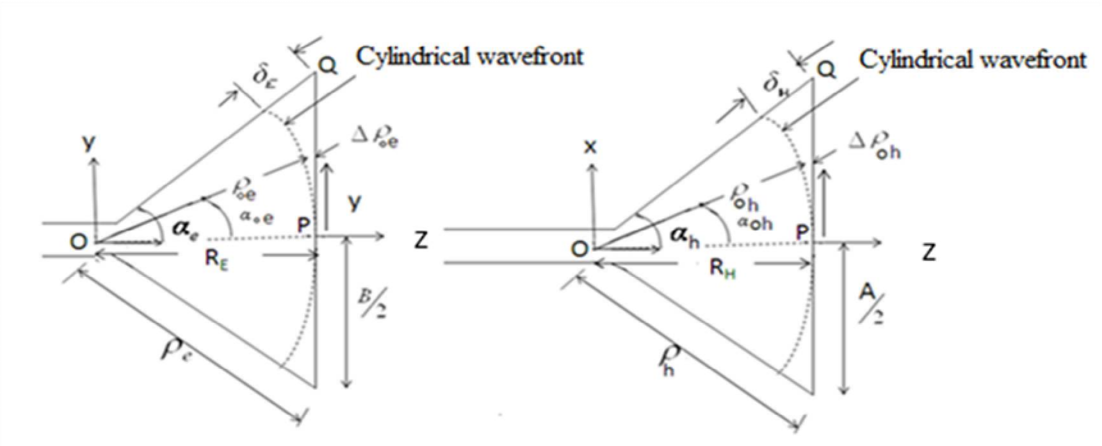

(a) **(b)**

Fig. 5 Geometrical relationship in horn (a) for the E-plane, and (b) for the H-plane

Since the aperture field is linearly polarized along y direction, the radiated magnetic field components at point P (r', θ', Φ') with respect to horn coordinate system (x', y', z') are given by[8]

$$H_{\theta}' = -j\frac{e^{-jkr'}}{2\eta\lambda r'}\sin\phi'(1+\cos\theta')\int_{-\frac{A}{2}}^{\frac{A}{2}}\int_{-\frac{B}{2}}^{\frac{B}{2}} E_0\cdot\cos\left(\frac{\pi}{A}x'\right)\cdot e^{-j\left(\frac{kx'^2}{2\rho_{0h}}+\frac{ky'^2}{2\rho_{0e}}\right)} e^{jk(x'\sin\theta'\cos\phi'+y'\sin\theta'\sin\phi')}dx'dy' \quad \text{---- (5)}$$

$$H_{\phi}' = j\frac{e^{-jkr'}}{2\eta\lambda r'}\cos\phi'(1+\cos\theta')\int_{-\frac{A}{2}}^{\frac{A}{2}}\int_{-\frac{B}{2}}^{\frac{B}{2}} E_0\cdot\cos\left(\frac{\pi}{A}x'\right)\cdot e^{-j\left(\frac{kx'^2}{2\rho_{0h}}+\frac{ky'^2}{2\rho_{0e}}\right)} e^{jk(x'\sin\theta'\cos\phi'+y'\sin\theta'\sin\phi')}dx'dy' \quad \text{---- (6)}$$

III. ANALYSIS OF RADIATION CHARACTERISTICS OF REFLECT ARRAY ANTENNA

In this analysis horn is considered in (x', y', z') coordinate and the microstrip array is defined in (x, y, z) coordinate as shown in Fig.3. The positional coordinates of array element are determined for different elements spacing and sizes using MATLAB. The radiation field from feed horn is determined at these points using appropriate coordinate transformation from prime to unprimed system. After that the current at each of the element is determined. This leads to know the current distribution in array elements. From the knowledge of current distribution the radiation field or array factor of total reflect array is determined.

MxN Array (odd) case: each element= LxW
Edge to edge spacings: dx along x and dy along y
Successive center to centre spacings:
hx =dx+L and hy =dy+W
OA=xi =2hx =(i-1)hx ; i=(M-1)/2
AB=yj =2hy =(j-1)hy ; j=(N-1)/2
OB= $\sqrt{(x_i^2 + y_j^2)}$

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Transform r', θ', φ' of horn radiation pattern into xi and yj i.e., (i-1)hx and (j-1)hy

Co-ordinates transformation

$x' = r' \sin\theta' \cos\phi'$ $x = -x' = -r' \sin\theta' \cos\phi'$

$y' = r' \sin\theta' \sin\phi'$ $y = y' = r' \sin\theta' \sin\phi'$

$z' = r' \cos\theta'$ $z = R - z' = R - r' \cos\theta'$

The radiated fields of the reflect array have been computed from the equivalent induced electric current densities $\vec{J}_s = \hat{n} \times (\vec{H}_i + \vec{H}_r)$ on the front surface of the array. Here $\vec{H}_i =$ the field on the patches incidents from horn radiation and $\vec{H}_r$ =reflected field on the patch surfaces, and $\hat{n}$ is the unit vector normal to the reflector surface at the point of reflection.

Applying boundary condition on the metallic reflector surface electric current density is determined from the magnetic field on the patches:

$$\vec{J}_s = \hat{n} \times (\vec{H}_i' + \vec{H}_r') = 2\hat{n} \times \vec{H}_i' \quad \text{---- (7)}$$

$$\vec{H}_i' = \hat{\theta} H_\theta' + \hat{\phi} H_\phi' \quad \text{---- (8)}$$

In order to determine the induced currents on the patch elements following Co-ordinate transformations are made in Eqns.(1.3) and (1.4)

$$x' = r' \sin\theta' \cos\varphi' = -x$$

$$y' = r' \sin\theta' \sin\varphi' = -y$$

$$z' = r' \cos\theta' = R - z$$

Here R is the far field distance between horn aperture and the surface of the reflect array.

Array Factor of reflect array

After calculating the surface current for each patch, the array factor is computed by substituting the respective magnitude and phase of the surface current in the array factor equation for equally spaced array with non-uniform excitation amplitude. The general array factor is given by

$$AF(\psi) = \sum_{m=0}^{N-1} a_m e^{jm\psi} \quad \text{---- (9)}$$

Here, a0, a1, a2,…, am are the excitation amplitudes of the respective rectangular patches, and ψ is the phase difference between successive elements.

Since beam steering in space involves both θ and Φ angles, inter-element phase shifts are required in two orthogonal directions (X and Y) in two-dimensional reflect array. Let the inter element spacing, inter element phase difference of excitation and the number of isotropic elements in x and y –directions are hx and hy, αx and αy, M and N, respectively.

The array factor will be in two orthogonal directions and are given respectively, by

$$AF_x = \sum_{m=0}^{M-1} a_m e^{jm\psi_x} \quad \text{---- (10)}$$

and

$$AF_y = \sum_{m=0}^{N-1} a_n e^{jn\psi_y} \quad \text{---- (11)}$$

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Where,

$$\psi_x = \frac{2\pi h_x}{\lambda}\sin\theta\cos\varphi + \alpha_x \quad \text{---- (12)}$$

$$\psi_y = \frac{2\pi h_y}{\lambda}\sin\theta\sin\varphi + \alpha_y \quad \text{---- (13)}$$

Ψx and Ψy are the phase difference of the radiation field point from two consecutive sources in x and y directions and αx, αy are the consecutive inter-element phase difference in x and y directions, respectively.

Total Array Factor, $AF = AF_x \times AF_y$ (14)

Normalized Array Factor, $NAF = \frac{AF}{AF_{max}}$ (15)

The radiation pattern of the reflect array is computed from the array factor equation using MATLAB. The basic definition of other important parameters as stated in case of parabolic hold good:

IV. RESULTS OF INVESTIGATION

It has been observed that for both 11x11 and 51x51 array produce better results in terms of side lobe level for array spacing progressively decreases in accordance with arithmetic progression. $d = \lambda/8 - (\mathrm{m}-1)\lambda/(3\times\mathrm{P})$; P=(M-1)/2, m= 1 for center element; m=1,2,3…. (M+1)/2, where M is the total number of elements along a given axis. Theoretical results for 11 x 11 elements with uniform and AP spacing are shown in Fig 6.

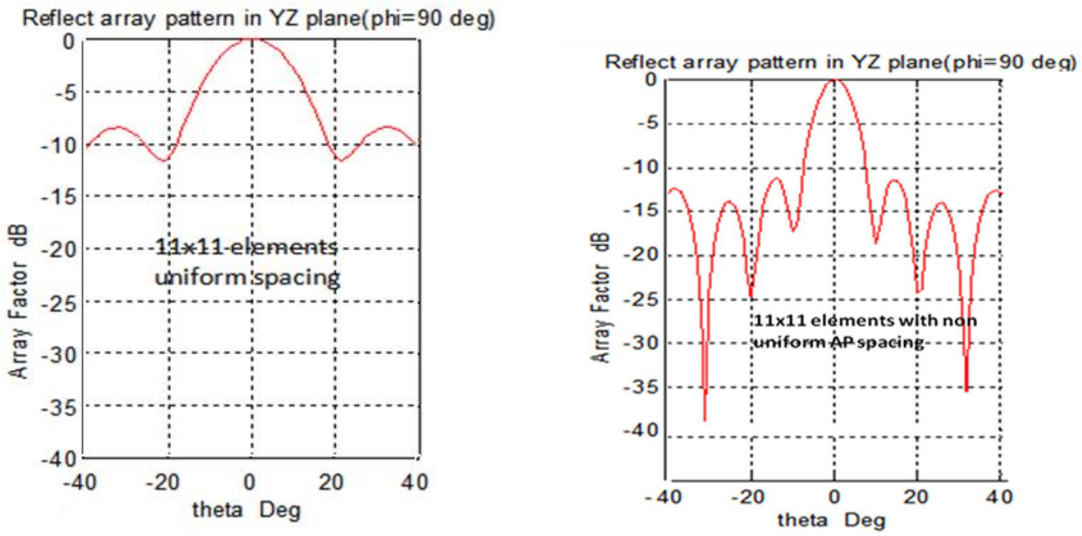

Fig. 6 Reflect array radiation patterns for 11 x 11 elements

In order to obtain experimental results a large size reflector array with 51 x 51 elements is designed and fabricated with element size $\lambda/2 \times \lambda/2$ and inter element spacing $d = \lambda/8$. A photograph of the experimental set using gun diode source and horn feed is shown in Fig.7.

Both the theoretical and experimental results are shown in Fig 8. Due to sensitivity limitation of the measurement set up, experimental results are limited to first side lobe only and matches well with the theoretical main lobe.

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Fig 7 Experimental setup

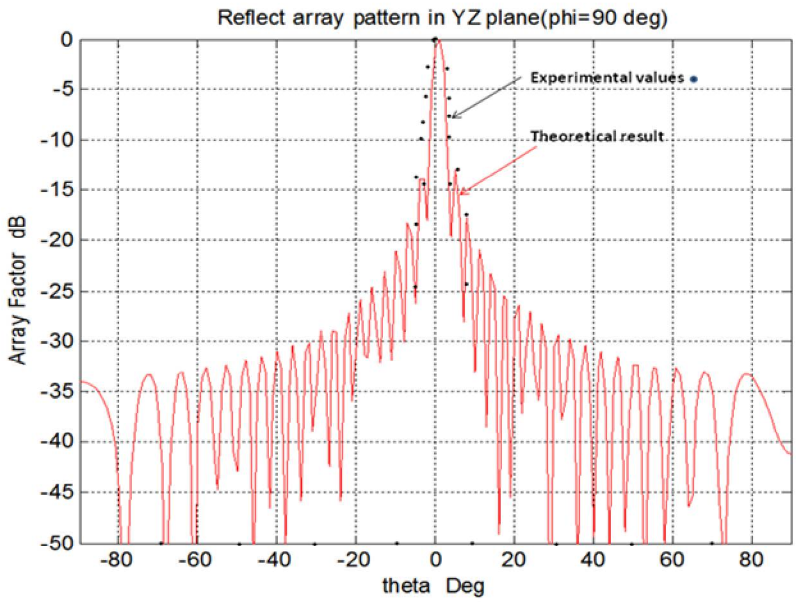

Fig 8. Reflect array radiation pattern for 51x51 elements

V. DISCUSSION AND CONCLUSION

Due to directional pattern of the feed, there is non-uniform phase distribution of illumination of the array. It is, therefore, necessary that elements are spaced non uniformly to satisfy the phase condition of Eqn,(1-2). Therefore, some improvement of the radiation pattern of the reflect array is observed for inter element spacing according to Arithmatic Progression.

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BIOGRAPHY

Antara Ghosal is presently assistant professor in the Dept. of ECE, GNIT, Kolkata. She obtained B.Tech degree in ECE and M.Tech degree in MCNT from West Bengal University of Technology in 2009 and 2011, respectively. Her research interests are Electromagnetics, microstrip antenna, mobile communication. She is a member of IEEE.

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Annapurna Das obtained M.Sc. degree in physics from University of Calcutta, M.Tech degree in Microwave Electronics and Ph.D degree in Electrical Engineering from the University of Delhi. She worked in the Department of ECE, Anna University during 1985-2007 as Professor. Presently she is Director of GNIT, Kolkata. She is the author of Engineering Text Book "Microwave Engineering", published by Mc-Graw Hill, USA, Singapore and India and co-author of the text book "Antenna and Propagation", and published by Mc-Graw Hill Education.She is the life member of Society of EMC Engineers (India) and ISTE. Her current interests are microwaves, EMI/EMC and Microstrip Antenna.