Field Pattern computation using 2 - D FFT for Microstrip Reflectarray Antenna

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Abstract*: A Microstrip Reflectarray antenna as a planar array antenna is examined in this study effort. The basic original design requires that the phase of the field reflected from a Microstrip Reflectarray element be set so that the overall phase delay from the feed to a fixed aperture plane in front of the Reflectarray is constant for all elements. The array factor and element pattern product are displayed in the overall electric field pattern expression. The arrangement of Microstrip Reflectarray antenna and feed has been placed in prime focal axis. Amplitude tapering is used to improve the main beam's field strength by lowering the side lobe levels. The comparative numerical analysis of computing field pattern normally as well as using 2-D FFT of n x n elements of the Microstrip reflectarray antenna is carried out using MATLAB codes. It is shown that MATLAB simulation time with FFT is much shorter than simulation time without FFT.

***Keywords*:. Microstrip Reflectarray antenna, array factor, amplitude tapering, resonant elements, Field pattern, 2 – D Fast Fourier Transform.**

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I. Introduction

In spaceship, the dimension and weight of the sub system plays an important role. As a substitute of it, a high gain antenna plays an important role in the telecommunication transmission and reception of signals that renders mass and dimension of the spaceship. A parabolic reflector radiates efficiently but they consume large amount of mass in the spaceship as well as it will be difficult to manage mechanically due to its curved reflecting surface.

A flat reflector named as a microstrip reflectarray was proposed as a future candidate high-gain antenna, a printed low - profile and a very thin and flat reflecting surface [1]. The Microstrip reflectarray is a flat reflector significantly suitable to be carried into the satellite compared to the parabolic reflector.

The advantages of Microstrip patch or printed reflectarray over standard reflectarray for the space applications are as follows. First, Microstrip patch reflectarray saves volume and simplifies the mechanical design [2] in the launch vehicle due to its flat reflecting structure. Second, resonant elements of reflectarray have an ability to adjust the phase, thus it gives a very accurate contour beam shape with phase-only synthesis technique [3].Third, Microstrip patch reflectarray has effortless and consistent folding mechanism which helps to install easily on spacecrafts. Fourth, fabrication can be done with low - cost photo-etching technique.

Reflectarray is an array of antennas, which is illuminated by primary feed horn instead of conventional transmission line feeds. The elements of reflectarray receive and then reradiate the incident energy of the feed horn with a given phase determined by the phase shifting device attached to the elements [4, 5]. The novel structure of the placement of the resonant elements in the rectangular grid enhances the bandwidth [6, 7].

In this investigation work, a Microstrip Reflectarray as a planar array antenna is considered. When feed is illuminated on this antenna, we get the reflected field.

This reflected field is analyzed here using MATLAB as a simulation tool. The major part of the research is carried out to find the computation time of field pattern when large number of resonant elements in the Microstrip patch reflectarray is used.

The computation is carried out by calculating the field pattern using 2 – Dimensional Fast Fourier Transform technique [7]. Also comparison of computation time of analyzing field pattern with 2 – Dimensional Fast Fourier Transform and without Fast Fourier Transform has been done.

II. Numerical Aspect

Consider a Reflectarray with unit cells placed in a rectangular grid separated by dx on the x-axis and dy on the y-axis. Reflectarray and feed are positioned at prime focal in the global coordinate axis [8, 9]. As illustrated in Fig. 1, Microstrip Reflectarray antenna can be guided in elevation (θ) plane and azimuth $(\emptyset)$ plane.

The elements are placed in the $2Nx + 1$ rows with common dx spacing. Each row contains $2Ny + 1$ elements with dy spacing. The positional coordinates and current distribution of mn^{th} element are mdx and ndy, where $-Nx \leq m \leq Nx$ and $-Ny \leq n \leq Ny$ and I_{mn} respectively.

The primary original design mandates that the phase (ψ_{mn}) of the field reflected from a Reflectarray element be chosen in such a way that the total phase delay from the feed to a fixed aperture plane in front of the Reflectarray is constant for all elements.

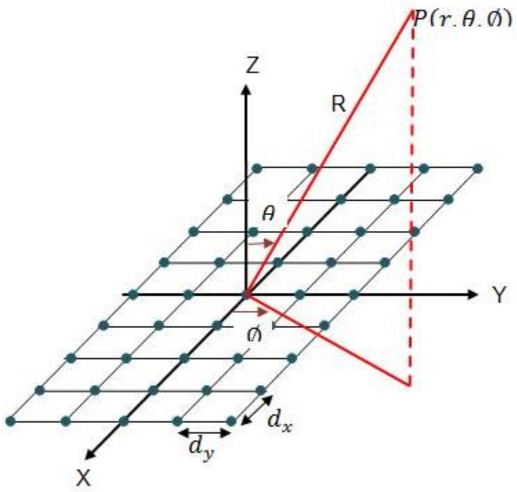

Fig. 1. Planar array with rectangular grid geometry.

To simplify the directional cosine terms, the resultant electric field pattern can be expressed in terms of u – and v – coordinates as shown in (1a) and the visible region has been found in (1b).

$$u = \sin\theta\cos\emptyset \text{ and } v = \sin\theta\sin\emptyset \quad (1a)$$

$$\sqrt{u^2 + v^2} \leq 1 \quad (1b)$$

The equal phase delay requirement provided by [9] is the fundamental design equation for focusing the beam in the desired direction $(r_0, \theta_0, \varphi_0)$.

$$\beta(R_{mn} - r_{mn}.r_o) - \psi_{mn} = 2\pi \quad (2)$$

Where β the free space wave number at the operating frequency, Rmn is is the distance from the feed to the mn[th] array element, and r_{mn} is the position vector from the array's centre to the mnth element and r_o is the unit vector pointing in the direction of the reflectarray antenna's primary beam.

The resonant length of the mnth patch element or patch stub is then chosen to induce a phase shift in the field reflected from the element [10, 11]. Fig. 2 depicts these characteristics.

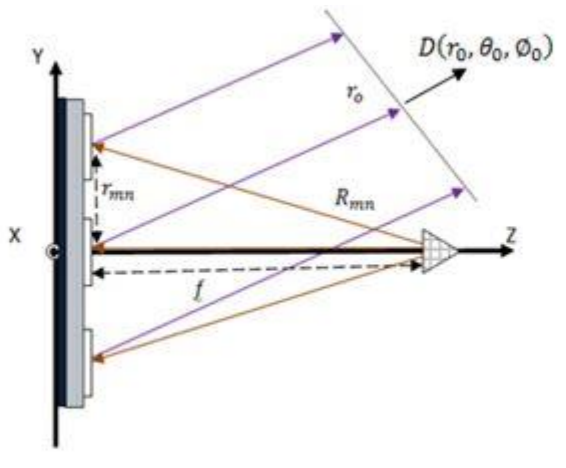

Fig. 2. Microstrip Reflectarray Antenna Design

The feed is f distance from the centre of Reflectarray and the coordinates of the mn[th] patch.

$$r_{mn} = x_{mn}.\hat{x} + y_{mn}.\hat{y} \quad (3a)$$

$$R_{mn} = \sqrt{x_{mn}^2 + y_{mn}^2 + f^2} \quad (3b)$$

$$r_0 = \sin\theta_0 .\cos\emptyset_0.\hat{x} + \sin\theta_0 .\sin\emptyset_0.\hat{y} + \cos\theta_0 .\hat{z} \quad (3c)$$

As a result, the entire array factor may be written as,

$$AF(\theta,\emptyset) = \sum_{m=-M}^{M} \sum_{n=-N}^{N} e^{j(M_x\psi_x)} e^{j(N_y\psi_y)} \quad (4a)$$

$$M_x = \frac{(2m-1)}{2} \text{ and } N_x = \frac{(2n-1)}{2} \quad (4b)$$

$$\psi_x = \beta d_x \sin\theta.\cos\emptyset = \beta d_x u \quad (4c)$$

$$\psi_y = \beta d_y \sin\theta.\sin\emptyset = \beta d_x v \quad (4d)$$

The total electric field pattern expression displays the array factor and element pattern product. The element pattern or feed pattern can be represented as $\cos^q\theta$, which is regarded as unity in this context. The power pattern is obtained by squaring the field pattern of the feed antenna.

$$E(\theta,\emptyset) = AF(\theta,\emptyset).\cos^q\theta \quad (5)$$

Amplitude tapering is used to increase the field strength of the main beam by reducing the side lobe levels. This is accomplished by arranging the unit cells in a rectangular grid with a circular form. The rectangular design planar reflectarray antenna's corner components have been eliminated.

III. Array Factor Computation using 2 – D FFT

For the fast computation of the reflectarray antenna's radiation pattern, an efficient tool is required. As the number of elements in the reflectarray antenna grows, so does the calculation time for computing the array factor. As demonstrated in [6,] the Fast Fourier Transform (FFT) technique aids in reducing calculation time.

For computation of n resonant elements using direct computation method needs n^2 complex multiplications and $n^2 - n$ complex additions. The computation of n resonant elements using FFT needs $\frac{N}{2}\log_2 N$ complex multiplications and $N\log_2 N$ complex additions. For n = 64, 4096 complex multiplications and 4032 complex addition need in linear form, thus increasing the delay in result. While in FFT, it needs on 192 and 384 complex multiplications and additions respectively. This shows that FFT is 10.67 times more efficient than direct computation method.

Let W_{mn} and $\emptyset_{mn}$ denotes the tapering sequence and phase shifting sequence respectively as shown in Fig. 3.

The two dimensional FFT of the sequence W (p, q) is defined as

$$W(p,q) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} W_{mn} e^{-j\left(\frac{2\pi mp}{M}\right)} e^{-j\left(\frac{2\pi nq}{N}\right)} \quad (6)$$

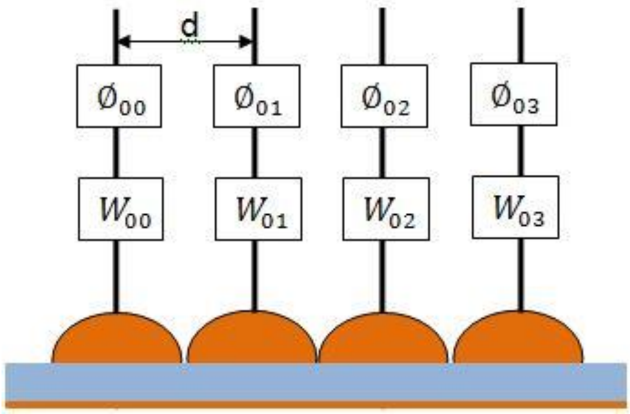

Fig. 3. Microstrip Reflectarray Phase shifting sequency.

The entire electric field is denoted by,

$$\therefore E(u,v) = e^{jA} e^{jB}\, W(p,q) \quad (7)$$

Where,

$$u = \sin\theta \cos\emptyset = \frac{\lambda p}{M d_x} \quad (8a)$$

$$v = \sin\theta \sin\emptyset = \frac{\lambda q}{N d_y} \quad (8b)$$

$$\frac{2\pi mp}{M} = \beta d_x \frac{mp}{M d_x} = \Delta\emptyset_v \text{ and } \frac{2\pi nq}{N} = \Delta\emptyset_v \quad (8c)$$

$$A = \beta d_x u\left(\frac{M-1}{2}\right) \text{ and } B = \beta d_x v\left(\frac{N-1}{2}\right) \quad (8d)$$

IV. Field Pattern Of Microstrip Reflectarray Antenna

The n x n elements used in the Microstrip reflectarray antenna having an element spacing of 0.7λ x 0.7λ in x - axis and y - axis respectively. The operational frequency is 13.4 GHz. The reflectarray is located at (0, 0, 0) position and feed is located at focal distance from the reflectarray antenna. The numerical analysis is carried out in MATLAB. The planar Microstrip reflectarray antenna employs amplitude tapering to achieve lower side lobe levels. The field pattern of 16 x 16 array components is illustrated in Fig. 4, with main lobe amplitude of 26.41 dB and first side lobe amplitude of 5.21 dB. The side lobe level is -21.21 dB down the main beam.

A circular shape is implemented on the planar grid of the microstrip reflectarray antenna. Out of 256 elements only 208 resonant elements of microstrip reflectarray antenna are used. The edge resonant elements of the microstrip reflectarray are neglected on the planar grid in order to implement array tapering. The placement of resonant elements on the planar Microstrip Reflectarray antenna is shown in Fig. 5. The resonant elements are spaced 0.7λ from each other in x – direction as well as y – direction. The center element of Microstrip reflectarray antenna is positioned at (0, 0).

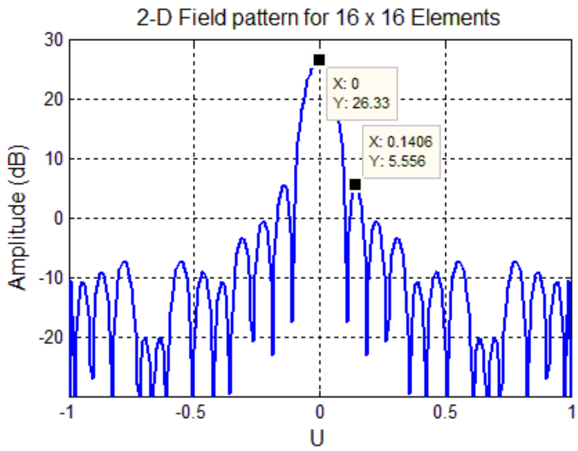

Fig. 4. 2 – Dimensional Field pattern for 16 x 16 Microstrip Reflectarray antenna.

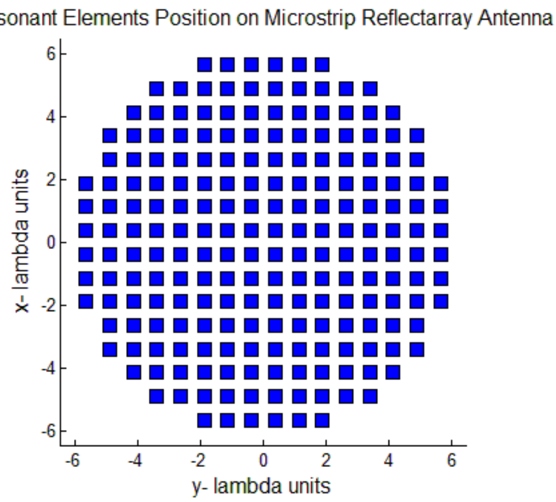

Fig. 5. Position of 208 Resonant Element in Microstrip Reflectarray Antenna.

V. Field Pattern Compution Using 2 – D FFT

Microstrip reflectarray antenna will reflect the electromagnetic waves illuminated by feed antenna. 2 – D FFT is used to compute the field pattern in U – and V – coordinates. Fig. 6 shows the field pattern for 208 resonant elements placed in circular shape aperture of rectangular grid structure. It is observed that at edges the field pattern values reaches to zero. While the resultant field pattern computed using 2 – D FFT gives maximum radiation in prime focal direction.

The comparative numerical analysis based on the field pattern calculation of n x n elements of Microstrip reflectarray antenna is shown in the table I.

The simulation time taken by MATLAB without using 2 – dimensional Fast Fourier Transform increases with increase in number of n x n resonant elements. For 64 x 64 Microstrip reflectarray antennas the simulation time of calculating field pattern without using FFT takes 23 minutes compared to 9 seconds using FFT. Here the loop of u – direction and v – direction is created to calculate the values shown in (1) to (5) equations. Along with it each computation is carried out for a particular resonant element in reflectarray located at 0.7λ distance from each other.

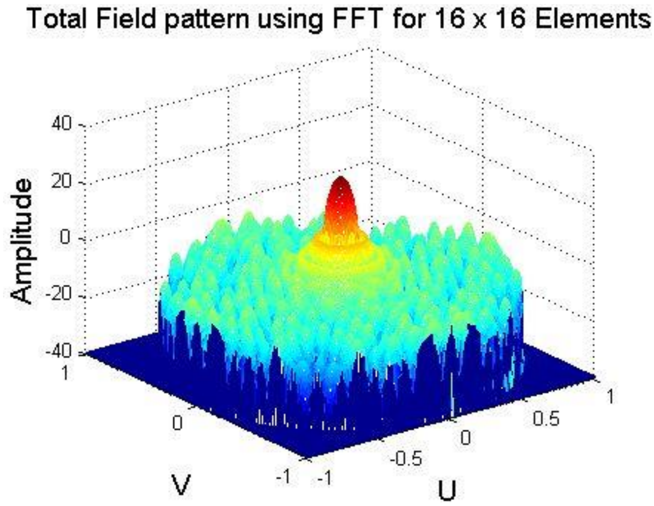

Fig. 6. Field Pattern of 16 x 16 resonant elements of Microstrip Reflectarray Antenna.

TABLE I. SIMULATION TIME FOR COMPUTING FIELD PATTERN

Resonant Elements (n)	Time Taken by MATLAB to compute Field Pattern	
	Without FFT (seconds)	*With FFT (seconds)*
2	1.67	1.03
4	4.36	1.04
8	22.43	1.06
16	78.35	1.32
32	320.93	2.78
64	1372.69	9.12

Table I also depicts the simulation time of n x n elements used in the Microstrip reflectarray antenna having an element spacing of 0.7λ in x-axis and y-axis respectively is carried out in MATLAB using FFT. It is clearly understood that simulation time using FFT is very less compared to that without using FFT.

VI. CONCLUSION

A Microstrip Reflectarray as a planar array antenna is examined in this study effort. The reflected field is obtained when the feed is lit on this antenna. This reflected field is examined here using MATLAB as a modeling tool.

The basic original design requires that the phase of the field reflected from a Reflectarray element be set so that the overall phase delay from the feed to a fixed aperture plane in front of the Reflectarray is constant for all elements. The array factor and element pattern product are displayed in the overall electric field pattern expression.

The 16 x 16 resonant elements of Microstrip reflectarray antenna are spaced with 0.7λ x 0.7λ in x - axis and y - axis respectively. The arrangement of Microstrip Reflectarray antenna and feed has been placed prime focal axis. The electric field has been computed using MATLAB with main beam amplitude 26.41 dB and 1st side lobe is down by -21.21 dB. This results in generation of steep main lobe without any generation of grating lobes. Amplitude tapering is used to improve the main beam's field strength by lowering the side lobe levels. This has been done by placing 208 resonant elements in a circular aperture shape on a rectangular grid.

The comparative numerical analysis of computing field pattern normally as well as using 2-D FFT of n x n elements of the Microstrip reflectarray antenna is carried out using MATLAB codes. As shown in Table I, the simulation time taken by MATLAB without applying the two-dimensional Fast Fourier Transform rises as the number of n x n resonant elements increases. It is obvious that simulation time with FFT is much shorter than simulation time without FFT.

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