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Effects of Array Parameters on FSS Structure of Dipole Array

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Abstract— ***This paper focuses on the study of the effects of the array parameters such as array spacing, length and width of the array element on the characteristics such as transmission coefficient, bandwidth of a Frequency Selective Surface (FSS) structure formed by uniform dipole array used in microwave frequency for communication. In this paper FSS structure of 20X20 half-wave dipole elements has been studied. Electromagnetic wave equations are solved by Method of Moment (MoM) and mathematical formulation has been programmed using MATLAB.***

Index Terms—***Frequency Selective surface, Half-Wave dipole, Periodic Array.***

I. INTRODUCTION

Two-dimensional planar periodic structure has attracted a great amount of attention because of its frequency filtering property. A periodic array consisting of conducting patch or aperture elements [1-3] is known as a frequency selective surface or dichroic. Similar to the frequency filters in traditional radio frequency (RF) circuit, the FSS may have band-pass or band-stop spectral behavior depending upon the array element type (i.e. patch or aperture). In the last two decades many fascinating FSS applications and sophisticated analytical techniques have emerged. Applications are the multi-band FSS in reflector antennas and the band pass radome. In very recent the application of FSS has also reached into household appliances as in microwave ovens.

In a dual reflector antenna system an FSS can be used Raj Mitra et. al. [3] suggested the basis functions for different FSS structures such as (a) Rectangular aperture or patch, (b) Circular aperture or patch, (c) Thin dipole or slot, (d) Cross dipole or slot, (e) Jerusalem cross etc.

Numbers of works have been reported taking different element structures with different orientation [5-6]. All the papers have used the optimum element spacing. But this paper focuses on the variation of FSS structure's (constitute of simple half wave dipole) different characteristics with the longitudinal & vertical element spacing and with the dipole width.

II. THEORETICAL FORMULATION

The FSS structure made by the finite-length rods may have a reflection coefficient magnitude equal to one (i.e., when length is λ/2), while for infinitely long rod case will only at "DC." The equivalent circuits for the long rods are inductors and for finite elements have series capacitances associated with the gaps between the elements, resulting in the equivalent circuit of a series LC circuit as shown. Obviously only the latter will act like a true ground plane at the resonant frequency with no leakage, while the long rod case cannot

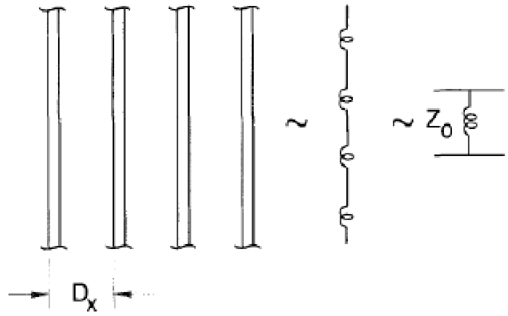

Figure-1(a)

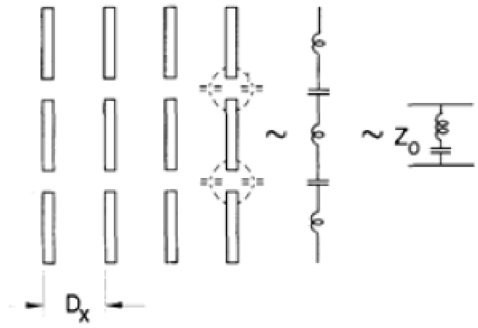

Figure-1(b)

Figure-1: Equivalent circuits (a) Infinite length (b) Finite length

In this paper the array of half wave dipole elements are used whose equivalent circuit is given in Fig.1(b). The frequency response of this simple circuit is nothing but a band pass filter. The electromagnetic fields equations are solved by Method of Moment in spectral domain to find out the transmission coefficient.

To formulate this method several assumptions have been made: -

(a) The FSS is infinite in extent, so that the diffraction from the edges of the surface in a practical situation is ignored.

(b) The incident radiation is a monochromatic plane wave and

(c) The conducting patches or the conducting screen has been assumed to be infinitesimally thin.

Starting from the Maxwell's equations given below (equation-1) and using the Lorenz condition we can achieve equation-2 for the time varying field

$$\nabla\times\vec{H} = \vec{J}+\frac{\partial\vec{D}}{\partial t}, \qquad \nabla\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} \quad ---->(1)$$

$$\vec{E} = -j\omega\mu\vec{A}+\frac{1}{j\omega\varepsilon}\nabla(\nabla\cdot\vec{A}) \quad ---> \quad (2)$$

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Where the symbols are their usual meanings

Free space Green's function due to unit current at a distance r', magnetic vector potential at a distance r is given by [11],

$$G(r, r') = \frac{e^{-jk_0|r-r'|}}{4\Pi\,|r-r'|} \qquad -->(3)$$

So, magnetic vector potential at a distance r, due to current J at a distance r' is given by,

$$A(r) = G * J = \int G(r, r')J(r')dr'$$

If we assume that r'=0 i.e. current J is considered at the origin, then

$$G(r) = \frac{e^{-jk_0 r}}{4\Pi r} \quad ----> \ (4)$$

In the plane z=0; $r = \sqrt{x^2 + y^2}$, Hence

$$\vec{G}(x,y) = \frac{e^{-jk_0 r}}{4\Pi r}\vec{I} = \frac{e^{-jk_0\sqrt{x^2+y^2}}}{4\Pi\sqrt{x^2+y^2}}\vec{I} \qquad -->(5)$$

$$\vec{A}(x,y) = \vec{G}(x,y) * \vec{J}(x,y) \qquad ------>(6)$$

* sign means the convolution operation]

The scattered electric field in free space in matrix form can be written as (after a few steps)

$$\begin{bmatrix} \vec{E_x}^s(x,y) \\ \vec{E_y}^s(x,y) \end{bmatrix} = \frac{1}{j\omega\varepsilon_0}\begin{bmatrix} \frac{\partial^2}{\partial x^2} + k_0^{\,2} & \frac{\partial^2}{\partial x \partial y} \\ \frac{\partial^2}{\partial x \partial y} & \frac{\partial^2}{\partial y^2} + k_0^{\,2} \end{bmatrix}\begin{bmatrix} \vec{A_x} \\ \vec{A_y} \end{bmatrix} \quad ---> \ (7)$$

After taking the Fourier transform and using the equation (6) and rearranging the equation (7) can be written as

$$\begin{bmatrix} \tilde{\tilde{E}}_x^{\,s}(\alpha,\beta) \\ \tilde{\tilde{E}}_x^{\,s}(\alpha,\beta) \end{bmatrix} = \frac{1}{j\omega\varepsilon_0}\begin{bmatrix} k_0^{\,2} - \alpha^2 & -\alpha\beta \\ -\alpha\beta & k_0^{\,2} - \beta^2 \end{bmatrix}\tilde{\tilde{G}}(\alpha,\beta)\begin{bmatrix} \tilde{\tilde{J}}_x(\alpha,\beta) \\ \tilde{\tilde{J}}_y(\alpha,\beta) \end{bmatrix} ---> (8)$$

Taking the inverse Fourier transform the scattered electric field is written as

$$\begin{bmatrix} \vec{E}_x^s(x,y) \\ \vec{E}_y^s(x,y) \end{bmatrix} = \frac{1}{(2\Pi)^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\frac{1}{j\omega\varepsilon_0}\begin{bmatrix} k_0^{\,2} - \alpha^2 & -\alpha\beta \\ -\alpha\beta & k_0^{\,2} - \beta^2 \end{bmatrix}\tilde{\tilde{G}}(\alpha,\beta)\begin{bmatrix} \tilde{\tilde{J}}_x(\alpha,\beta) \\ \tilde{\tilde{J}}_y(\alpha,\beta) \end{bmatrix} e^{j\alpha x}e^{j\beta y}\,d\alpha\, d\beta ---> (9)$$

On the conducting patch, the tangential electric field must vanish.

So, $E^s + E^{inc} = 0$ [on the conducting patch] i.e.

$E^s = -E^{inc}$, Hence

This formulation is valid for single patch only. To extend the spectral domain method to an infinite regular periodic array of patches in x and y direction satisfying Floquet's theorem for periodic structure and using the modified current densities equation (10) can be written as

Where

$$\alpha_m = \frac{2m\Pi}{a} + k_x^{\,inc}, \quad \beta_n = \frac{2n\Pi}{b} + k_y^{\,inc},$$

$$k_x^{\,inc} = k_0 \sin\theta\cos\phi, k_y^{\,inc} = k_0 \sin\theta\sin\phi$$

θ is the angle of incident wave with the z-axis and ϕ is the angle of the projection of the incident wave on the xy plane with the x-axis (Figure-5).

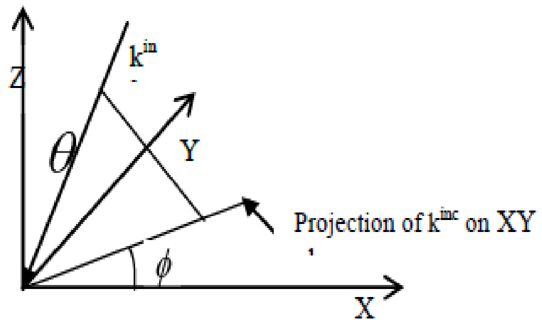

Figure-2

From these scattered electric fields $E_x^s(x,y)$ *and* $E_y^s(x,y)$; the transmission coefficients of the structure of mode mn due to mode kl incident is given by [11, 12, 13].

$$T_{TM} = \frac{j\omega\varepsilon_0 E_z^t}{\left(k_0^2 + \gamma_{mn}^2\right)}\sqrt{\frac{\gamma_{mn}\left(k_0^2 + \gamma_{mn}^2\right)}{\gamma_{kl}\left(k_0^2 + \gamma_{kl}^2\right)}} ------->(12)$$

Where

$$E_z^t = j\frac{(\alpha_m E_x^s + \beta_n E_y^s)}{\gamma_{mn}},$$

$$\gamma_{mn} = -j\left(k_0^2 - \alpha_m^2 - \beta_n^2\right)^{1/2} \qquad for\, k_0^2 > \alpha_m^2 + \beta_n^2$$

$$or, \quad -\left(\alpha_m^2 + \beta_n^2 - k_0^2\right)^{1/2} \qquad for\, k_0^2 < \alpha_m^2 + \beta_n^2$$

The equation-12 is programmed in MATLAB and the final solution has been obtained from the equation -12. The Transmission coefficient = (Transmitted Electric Field) / (Incident Electric Field). The incident field is taken as unity so the transmission coefficient is identical with the transmitted field in magnitude.

MOM method is used to find out E_z^t for easy and faster calculation Raj Mitra et. al. [3] suggested the basis functions for FSS structure comprising of array of dipole element.

III. RESULTS AND DISCUSSION

In this paper the simple half-wave dipole elements are taken as the array element of the FSS structure. The return loss and bandwidth variation of this FSS structure has been studied for different periodicity along horizontal (along X) direction and vertical (along Y) direction for a particular frequency. The same properties of the FSS structure have also been studied for different width of the dipole element. Table-I, II, III are the simulated results for the variations of the periodicity along X & Y axes and the width of the dipole. The variations are shown in Fig.-3-6. In Figure-1 it has been found that as the

The periodicity in both the direction is increased the return loss increased gradually. From the table-1 it is interesting to note that as we increase 'a' the higher 10dB cutoff frequency gradually increased whereas the lower 10dB cutoff frequency remain almost same. In table-2 it is found that as we increase 'b' the lower 10dB cutoff frequency gradually increased whereas the higher 10dB cutoff frequency remain almost same. Which means the bandwidth is increased gradually with increase of 'a' but it is decreases gradually for the increase of periodicity 'b' this is shown in Figure-4.

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Table-I

b=0.75λ , W=L/10 Resonant Frequency=9GHz	a (in λ)	Return Loss (dB)	Lower 10 dB cutoff freq. (GHz)	Higher 10 dB cutoff freq. (GHz)	BW (GHz)
	0.5	-33.15	8.82	10.12	1.3
	0.6	-35.18	8.82	10.21	1.39
	0.7	-36.32	8.83	10.43	1.6
	0.8	-37.15	8.84	10.67	1.83
	0.9	-38.06	8.85	10.86	2.01
	0.95	-38.55	8.85	11.13	2.28

Table-II

a =0.5λ, W=L/10 Resonant Frequency =9GHz	b (in λ)	Return Loss (dB)	Lower 10 dB cutoff freq. (GHz)	Higher 10 dB cutoff freq. (GHz)	BW (GHz)
	0.5	-51.33	8.45	10.26	1.81
	0.6	-55.91	8.6	10.32	1.72
	0.7	-58.96	8.82	10.2	1.38
	0.8	-55.98	8.9	10.39	1.49
	0.9	-62.69	8.91	10.3	1.39
	0.95	-76.66	8.95	70.35	1.4

Table-III

a = 0.5 λ, b = 0.75λ Resonant Frequency=9GHz	Width (in L)	Return Loss (dB)	Lower 10 dB cutoff freq. (GHz)	Higher 10 dB cutoff freq. (GHz)	BW (GHz)
	0.01	-50.37	8.63	10.53	1.9
	0.02	-49.16	8.63	10.51	1.88
	0.03	-48.61	8.64	10.49	1.85
	0.04	-47.8	8.65	10.48	1.83
	0.05	-47.38	8.67	10.48	1.81
	0.06	-45.33	8.7	10.49	1.79
	0.07	-43.91	8.73	10.54	1.81
	0.08	-41.82	8.76	10.61	1.85
	0.09	-40.24	8.8	11.19	2.39
	0.1	-38.55	8.85	11.13	2.28

The equivalent circuit of the FSS structure is shown in figure-2. Basically the equivalent circuit is a series LC circuit whose frequency response is like a bandpass filter. The upper cut off frequency is controlled by the value of inductor and the lower cut off frequency is depends on the value of the capacitor. If we increased the periodicity 'a' along X the value of the inductance is decreased as the electromagnetic waves linkage to the different dipole element is less which results the upper cutoff frequencies gradually increasing leads to the bandwidth enhancement. But if we increases the periodicity 'b' along Y direction the gap between the two dipole element increases which leads to decrease the capacitance value (since $C=\varepsilon A/d$). As the capacitance decreases the capacitive impedance increases which leads to increase the lower cutoff frequency but due to the presence of the inductive impedance in the total impedance term the increase lower cutoff frequency is not so rapid as for change in higher cutoff frequencies for variation of 'a'. Hence the bandwidth variation with the periodicity along Y is small compared to the variation of periodicity along X.

Figure-3 and figure-4 shows the variation of the return loss and bandwidth with the dipole width. Though the return losses decrease with increase of dipole width but the bandwith is remaining same upto .8L and maximum about .9L.

In electromagnetic theory for a dipole element it is assumed that the width of the dipole is infinitesimal and assumes the different point on the dipole as a point source. So as we increased the width of the dipole the return loss decreases. Due to the combined effect of the equivalent inductance and capacitance the lower and higher cutoff frequency gradually increases. The higher cutoff frequency increases more rapidly than the lower cutoff frequency which leads to the enhancement of the bandwidth.

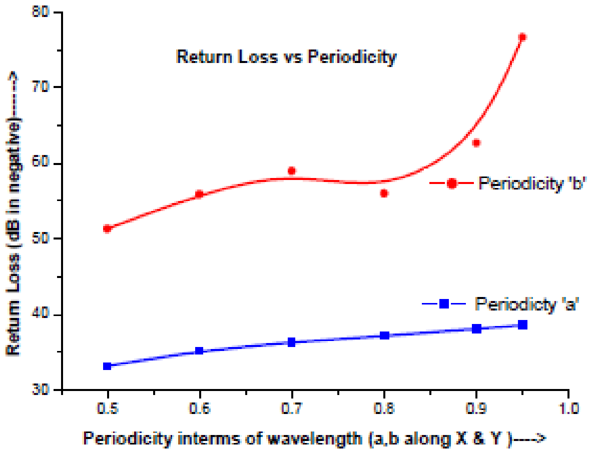

Figure-3

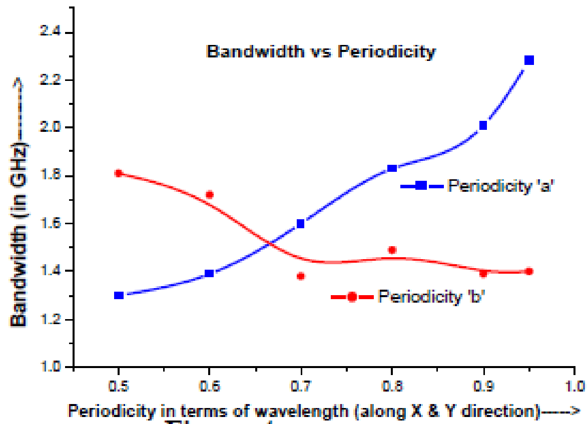

Figure-4

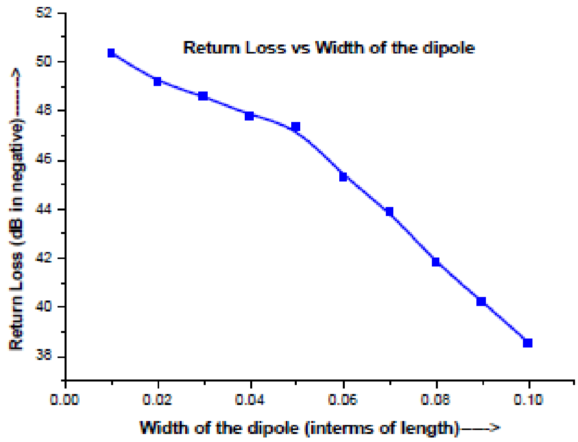

Figure-5

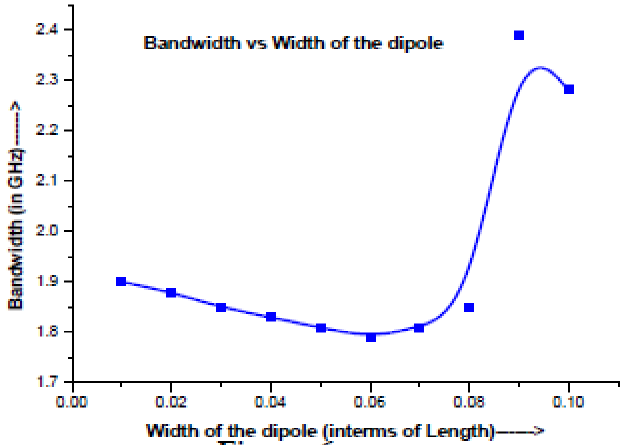

Figure-6

IV. CONCLUSION

In this paper the different characteristics, return loss & bandwidth, of the FSS structure consists of simple half wave dipole structure for different periodicities and dipole width have been studied. From the basic electromagnetic equations the transmission coefficients (in dB) is plotted against the frequency using the MATLAB programme. In this paper in finding the transmission coefficient the standard basis function for the dipole element has been used. In future this work can be extended for any other type of FSS element such as cross dipole, Jerusalem cross or any other type by using the proper basis functions.

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