Design and Performance Analysis of Linear Array

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***Abstract** - Abstract—In this paper two and four element arrays are designed using two different substrate materials and their performance is compared. Design is done at 2.4 GHz. Simulated results of four elements array using both material (Arlon AD250 lossy and FR-4) are presented here. It shows that with Arlon substrate better gain and low side lobe levels with adequate bandwidth are achieved. Optimization with Arlon material shows good results. Simulation is done using CST EM simulator.*

Keywords— Antenna gain, MSA, Return loss , 2.4GHz

1. INTRODUCTION

Massive many input many output antenna array is the need of today's wireless generation. Requirement of data rate is increasing day by day with miniaturization in antenna size. With increasing requirements for personal and mobile communications, the demand for smaller and low profile antennas has brought the Microstrip antenna to the forefront, [1]. Microstrip antenna are mostly preferred because of its light weight, low volume, low profile, planar configuration, this is possible due to conformal ,low fabrication cost and ease of mass production. Also linear and circular polarizations are possible, [2].

An MSA in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. Radiation from the MSA can occur from the fringing fields between the periphery of the patch and the ground plane. In this paper, rectangular patch antenna is designed at a frequency of 2.4 GHz. Two different dielectric materials are used one is low cost commercially available FR-4 with dielectric constant 4.4 with loss tangent of 0.025 and another is Arlon AD250 having dielectric constant of 2.5 and loss tangent 0.018. Arlon material combine the excellent low loss electrical properties of Poly Tetra Fluoro Ethylene(PTFE) resin. Stability of PTFE over a wide frequency range and low loss makes it ideal for a variety of microwave and R/F applications in telecom infrastructure, [3].

Antenna array [4][5] is one technique which improves the gain of antenna systems. It is the systematic arrangement of antennas working together for transmitting and receiving waves. It consists of identical antenna elements having identical orientation distributed in space. Based on geometrical configuration antenna arrays are classified as planar array and linear array. For a linear array, the antennas are placed along the Axis (straight line) of the array.

In this paper, arrays of Microstrip antenna are analysed using CST simulation tool. Section I gives design equation. Section II describes Microstrip antenna design. Section III elucidates design of multi element antenna with different substrate material and their performance. Finally conclusions of the paper are given in Section IV

2. A MICROSTRIP ANTENNA DESIGN

First single patch antenna is designed and then two and four element arrays are designed.

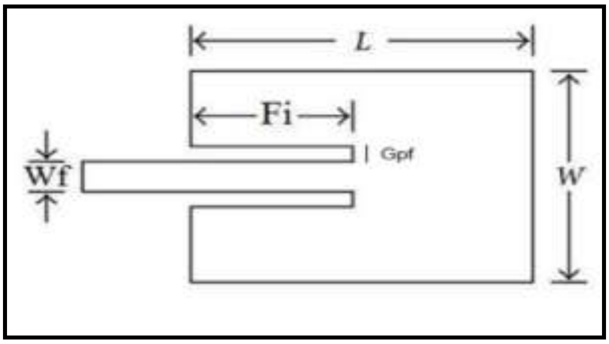

Fig -1: Rectangular microstrip antenna with inset feed

Single patch antenna is designed with resonant frequency at 2.4 GHz with FR-4 substrate having dielectric constant of 4.4 and thickness of 1.6mm. Following design equations are used for finding length and width by specifying dielectric constant, loss tangent and thickness of it.

2.1 Mathematical equations for MSA parameter calculations

- For calculating width of patch antenna:

$$W = \frac{1}{2f_{r\sqrt{\mu_0\epsilon_0}}}\sqrt{\frac{2}{\epsilon_{r+1}}} = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_{r+1}}}$$

Where c =free space velocity of light

f_r = resonant frequency

ε_r = dielectric constant of substrate

- For calculation of effective dielectric constant:

$$\epsilon_{eff}= \frac{\epsilon_r+1}{2}+\frac{\epsilon_r-1}{2}\left(\frac{1}{\sqrt{\left(1+\frac{12*hs}{W}\right)}}\right)$$

Where hs= thickness of substrate

For calculation of actual length:

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. Dimensions of the patch along its length have been extended on each end by a distance ΔL, which is function of effective dielectric constant and width to height ratio(w/h). Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is

$L_{eff} = L + 2\,\Delta L$

where L is physical length.

$L= L_{eff} - 2\Delta L$

$$\frac{\Delta L}{hs} = 0.412\frac{(\epsilon_{eff+0.3})\left(\frac{W}{hs}+0.264\right)}{\left((\epsilon_{eff-0.258})\left(\frac{W}{hs}+0.8\right)\right)}$$

- Length and width of ground plane:

$L_g = 2*L$

$W_g = 2*W$

- Length of inset feed:

$F_i=10^{-4}(0.001699*\varepsilon_r^7+0.13761*\varepsilon_r^6-6.1783*\varepsilon_r^5 +93.187*\varepsilon_r^4-682.69*\varepsilon_r^3-256.19*\varepsilon_r^2-4043*\varepsilon_r)*L/2$

To design microstrip feed line (inset feed):

The input impedance (Zc) is usually 50Ω.

The width of inset feed (W_f) is calculated as

$$Z_c= \frac{60}{\sqrt{\epsilon_{eff}}}\ln\left[\frac{8h}{w_f}+\frac{w_f}{4hs}\right] \qquad \frac{w_f}{h} :<1$$

$$= \frac{120\pi}{\sqrt{\epsilon_{eff}}\left[\frac{w_f}{hs}+1.393+0.667\ln\left(\frac{w_f}{hs}+1.444\right)\right]} \qquad \frac{w_f}{h}>1$$

Where w_f is the width of the microstrip line

- The gap between patch and inset feed (G_{pf}) is usually 1mm.

Thickness of ground plane (h_t) is taken as 0.35mm and height of substrate (h_s) as 1.6mm. Single rectangular patch with dimensions are given in table 1.

Table -1: List of parameter with dimensions

Parameters	Dimensions in mm
W	38
L	29
F_i	8.85
W_f	3.137
G_{pf}	1
L_g	76
W_g	58
h_t	0.035
h_s	1.6

2.2 Design of single patch with fr-4 substrate:

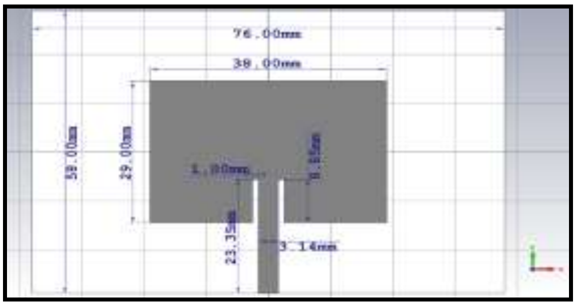

Fig -2: Single patch with inset feed

2.3 Simulated parameters of Antenna

Graph of return loss verses frequency and polar plot are shown in figure 3 and 4. From return loss plot bandwidth is calculated. As it is difference between two intersecting points on -10dB line. Simulated results of single patch are return loss S11 -21.038dB with Bandwidth 68MHz, as shown in figure3. Radiation pattern shows gain 3.23dB and side lobe level -12.7 dB as shown in figure 4.

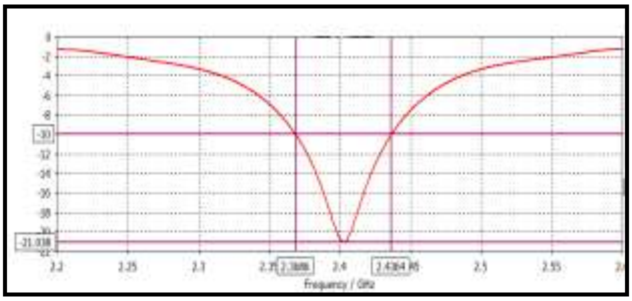

Fig -3: Return loss of single element antenna

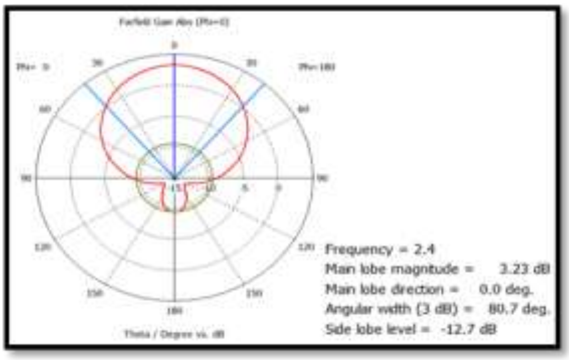

Fig -4: Radiation pattern (polar plot) of single element

3. DESIGN OF MULTI ELEMENT ANTENNA ARRAY

3.1 Design of two element array with corporate feed

The corporate-feed network is used to provide power splits of 2*n* (i.e., *n* = 2; 4; 8; 16; 32, etc.). This is accomplished by using either tapered lines or using quarter wavelength impedance transformers [1]. Corporate-fed arrays are general and versatile. With this method the designer has more control of the feed of each element (amplitude and phase) and it is ideal for scanning phased arrays, multi beam arrays, or shaped-beam array. Design for the same is shown in figure 5.

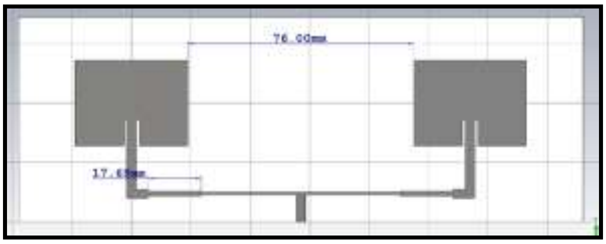

Fig -5: Two element antenna array

Quarter wave transmission line $Z_c = \sqrt{Z_1 * Z_2}$

Where Z_1 = 50 ohms and Z_2 = 100 ohms and Z_c = 70.71 ohms.

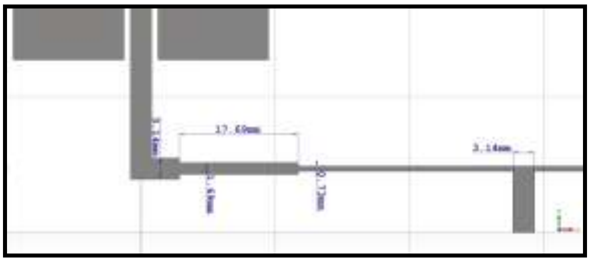

Fig -6: Two element antenna array with quarter wave transmission line

3.2 Simulated results of two element array:

Two element arrays are simulated at 2.4 GHz. Return loss S11 is -42.391db with Bandwidth 77.2 MHz as shown in figure 7. Radiation pattern (polar plot) shows gain 5.71dB and side lobe level -8.9 dB as shown in figure 8.

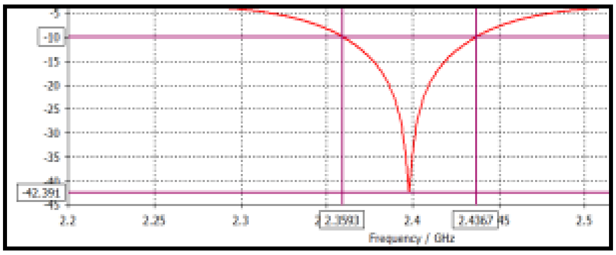

Fig -7: Return loss of two element array

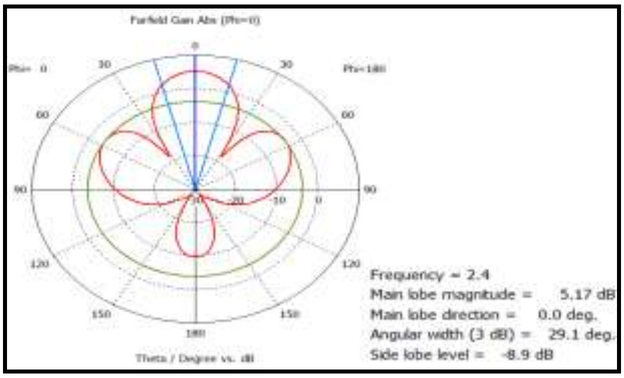

Fig -8: Radiation pattern (polar plot) of two element antenna array

3.3 Four element array

As shown in figure 9 four element antenna array are designed with 76.00mm spacing between the elements. These are placed linearly. Corporate feeding is used. Inset feeding and quterwave transformer are preferred for impedance matching.

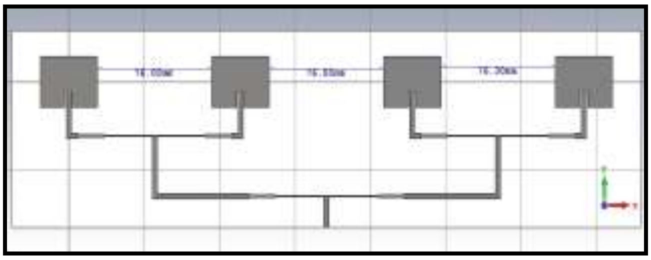

Fig -9: Design of four element antenna array

3.4 Simulated results of four element array

Graph of return loss verses frequency and polar plot are shown in figure. Simulated results of four element arrays have return loss S11 -25.194dB with Bandwidth 176.89MHz, as shown in figure 10. Radiation pattern shows gain 7.99dB and side lobe level -4.4 dB as shown in figure11.

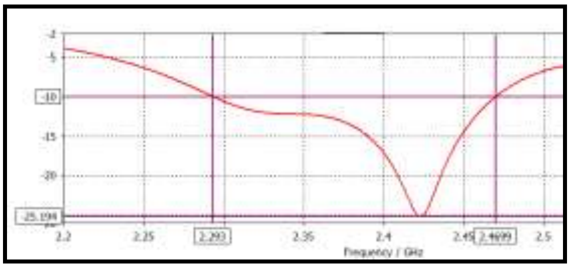

Fig -10: Return loss of four element array

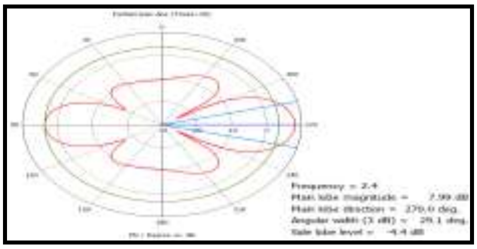

Fig -11: Radiation pattern (polar plot) of four elements

3.5 Design of single element with Arlon substrate.

Here single patch, two element array and four elements array are designed with arlon AD250 as substrate with dielectric constant as 2.5. Results shows increase in gain. These results are obtained after optimization which gives better results. With single patch return loss S11 is -28.72dB. Bandwidth 42.8 MHz as shown in figure 12. Radiation pattern shows gain 8dB and side lobe level -20 dB as shown in figure 13

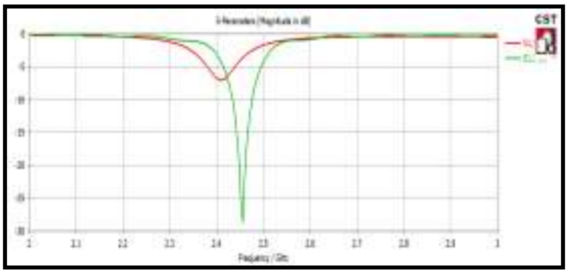

Fig -12: Return loss of single element (Arlon AD250)

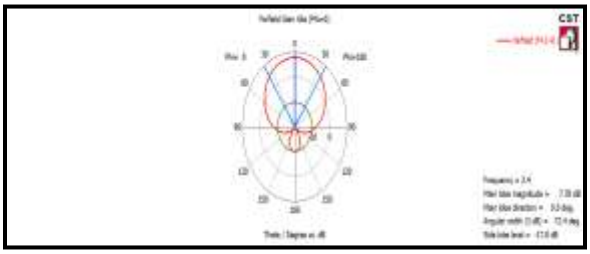

Fig -13: Radiation pattern (polar plot) of single element (Arlon AD250)

3.6 Four element array with arlon material is designed and simulated.

Simulated results of four element array antenna

Simulated results of four element array are return loss S11 -25.194dB with Bandwidth 176.89MHz.as shown in figure17. Radiation pattern shows gain 12.8dB side lobe level -16.3 dB as shown in figure14.

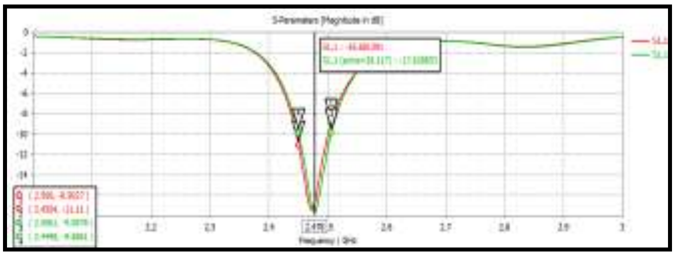

Fig -14: Return loss for four element array optimized

TABLE 2: Comparison of parameters for different elements

Sr. No	Substrate used	Elements	Return Loss in dB	Gain in dB	Bandwidth in MHz	Side lobe level in dB
1	FR-4	Single	-21.04	3.23	68.00	-12.7
2		Two	-42.39	5.71	77.20	-8.9
3		Four	-25.19	7.99	176.89	-4.4
4	Arlon	Single	-28.72	8.00	42.80	-28
5		Two	-16.90	9.76	37.50	-13.4
6		Four	-16.68	12.80	55.60	-16.4
7		Four (optimized)	-17.63	13.30	55.60	-15.4

4. CONCLUSIONS

By observing table 2 following conclusions are taken.

Higher gain and lower side lobe level are achieved with Arlon material when optimization for S11 is done. Optimization for single and four element array are done with frequency domain analysis and using trust region framework algorithm. High bandwidth is achieved with FR-4 material when four elements are used.

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