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Optimized Microstrip Patch Antenna (MPA) Array Design To Enhance Gain For S-Band Application

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Abstract : *The modern wireless communication system requires high gain, large bandwidth and minimal size antenna's which are capable to provide better performance. In this paper firstly optimized single element MPA is designed and then optimization of 1×2 array is achieved by using different spacing between array elements and finally 1×4 array is designed to achieve high gain. The impedance of corporate feed network of array is matched by using quarter wavelength transformer. The final antenna provides gain 14.45 dBi at resonant frequency 2.45 GHz .The antenna is designed on Rogers RT/duroid 5880 (tm) substrate by using Ansoft HFSS V.13 software. The antenna is suitable for S-band (especially for ISM) application*
Keywords: *wireless communication, microstrip patch antenna (MPA), array, corporate feed network, quarter wavelength transformer, resonant frequency, Ansoft HFSS, S-band, ISM*

I. Introduction

Antenna can be considered as backbone and almost essential part of wireless communication. The MPA is very simple to design consisting of a dielectric material, a patch and a ground plane. The uses of MPA are increased at a great deal for their attractive features such as low profile, low weight, low cost, ease of fabrication and integration with RF devices. But the performance of MPAs are fetched with lower gain and very narrow bandwidth[1],[2].The gain of MPA is increased by slightly increasing the dimensions of patch and multilayer structure [3]. In order to design a compact MPA, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. So optimization must be chosen between the antenna dimension and antenna performance [4], [5]. The antenna gain can be increased by increasing the number of antenna in array. The larger number of antenna elements, the better gain of antenna array is achieved, but size of antenna goes to giant. The MPA array offers some excellent advantages relative to other types of antennas [6], [7].The impedance of the load must be the same of the source. The quarter-wavelength transformer impedance matching technique is used to divide the power equally to all patches [8].To design an array we need a feed network which will connect all the elements. A series feed MPA array is formed by interconnecting all the elements with high impedance transmission line and feeding the power at the first element. The main limitation of the series feed arrays is the large variation of the impedance and beam-pointing direction overa band of frequencies. Another popular microstrip antenna feeding system is the corporate feeding. Corporate feed arrays are general and versatile [9].This is accomplished by using either tapered lines or using quarter wavelength impedance transformers [10]. In some papers the return loss is achieved high but gain is comparatively low [11], [12], [13]. Again in some papers gain is satisfactory but the return loss is comparatively low [14].So, an optimization is needed for better performance. In our design the impedance matching is done by using quarter wavelength transformer to achieve moderate power distribution, satisfactory return loss and excellent gain and directivity. Also the gain and directivity is improved through optimization of array elements spacing. According to FCC, the Industrial, Scientific and Medical (ISM) Systems uses the frequency range from 2.4GHz - 2.4835 GHz for scientific research. So to design optimized antenna array for ISM the operating frequency is chosen 2.45 GHz.

II. Design Methodology

2.1 Design of a Single MPA: We selected resonant frequency for our design is $f_0 = 2.45\ GHz$. A single antenna was designed on Roger RT/Duroid 5880 (tm) dielectric substrate that has dielectric constant, $\epsilon_r = 2.2$ and height, $h = 1.58\ mm$

Design parameters calculation:

- The width of antenna element :

$$w = \frac{c}{2f_0\sqrt{(\frac{\epsilon_r+1}{2})}} - - - -(1)$$

Where, $c =$ Speed of light in free space

- The length of antenna element :

$$L = L_{eff} - 2\nabla L - - - -(2)$$

Where,

$$L_{eff} = \text{ The effective length } = \frac{c}{2f_0\sqrt{(\epsilon_{reff})}}$$

$$\epsilon_{reff} = \text{The effective } \epsilon_r = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2\sqrt{(1+12\frac{h}{w})}}$$

$$\nabla L = \text{The length extension } = 0.412h\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)}$$

Calculation of Wavelength of propagation: $\lambda = \frac{c}{f_0\sqrt{\epsilon_{reff}}}$

Table 1. Values of Antenna Parameters

Design parameter	Value (mm)
Patch Width (W)	48.4
Patch Length (L)	40.5
Inset Distance	12.368
Inset Gap	2.434
Feed Length	37.298
Feed Width	4.868

After designing and simulating the return loss of the antenna is found -23.3579dB and the gain is found 7.722dBi atat 2.45 GHz. The current distribution, RL plot, radiation pattern and polar plot of gain (2D & 3D) are shown below**.**

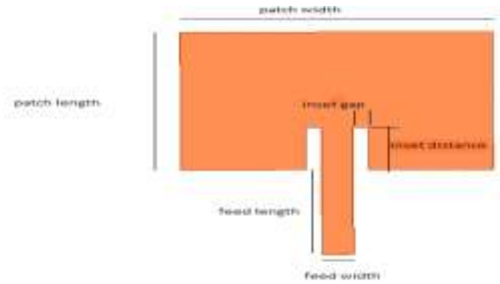


Fig. 1. Design of a single MPA

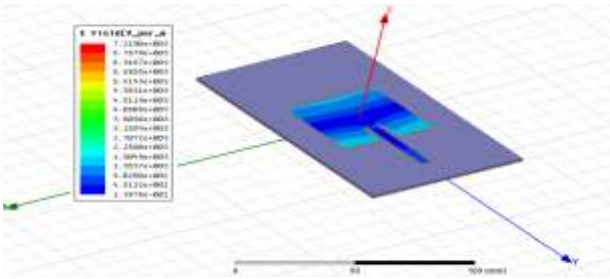


Fig. 2. Current distribution of single MPA

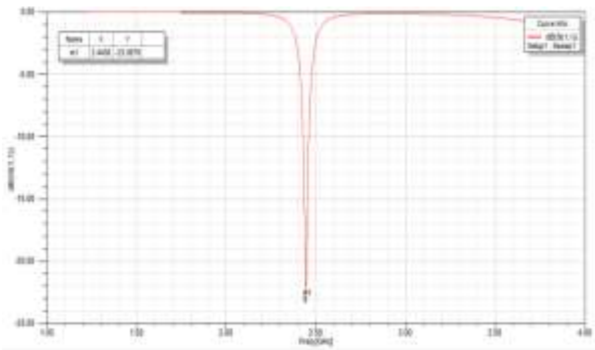


Fig. 3. Return loss of single MPA

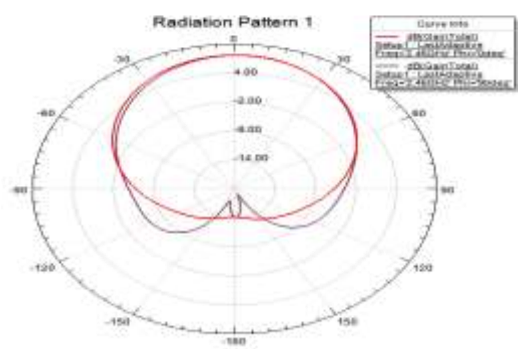
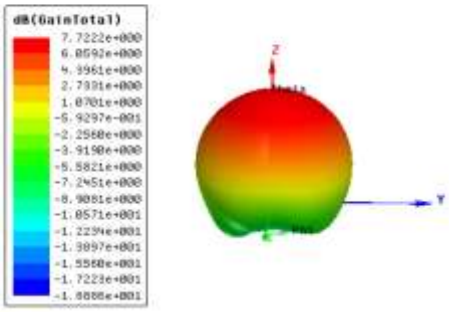


Fig. 4. Radiation pattern of single MPA



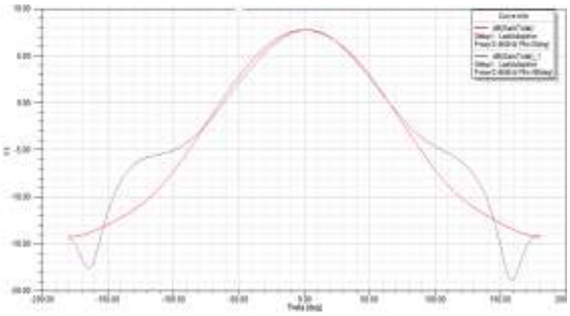
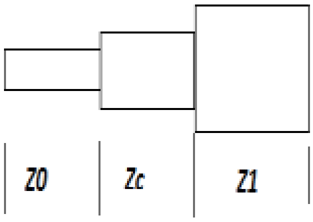


Fig. 5. Polar plot Gain of single MPA **Fig. 6** Gain of single MPAat φ=0_deg (E-plane)& 90_deg (H-plane)

2.2 1×2 antenna array Design: Fig. 8. Shows the configuration of 1x2 linear rectangular patch antenna array. To obtain 50Ω input impedance, feeding line width is calculated as W1=4.868 mm. This line is split into two 100Ω lines, with width of each W0=1.377 mm.

Quarter-wavelength transformer matches the 100Ω patches to a 50Ω transmission line [15], whose impedance is,

$$z_c = \sqrt{(z_1 * z_0)}$$
$$= 70.7\Omega$$



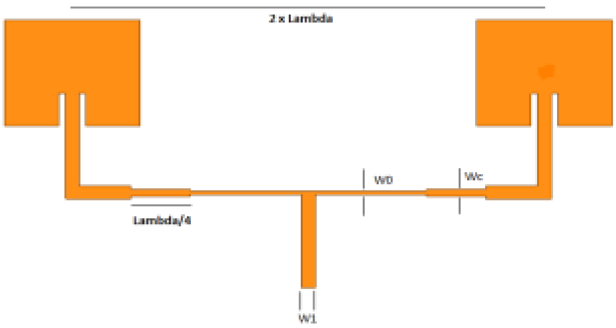


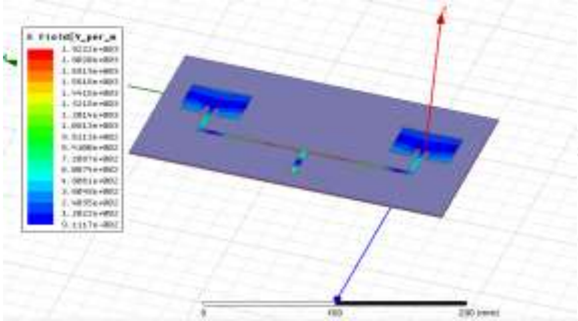
Fig. 7. Impedence matching by quarter wavelength transformer **Fig. 8.** Design of a 1×2 MPA array

We found the width of the quarter wavelength transformer at Zc = 70.7 Ω is Wc = 2.737 mm and Length is Lc=21.075. The spacing between two array elements is optimized at 2_Lambda as:

Table 2. Results of different spacing between elements

Space between elements	**Return Loss**(dBi)	**Gain** (dBi)
1λ	-17.52	10.10
1.5λ	-21.01	10.31
$\mathbf{2\lambda}$	**-22.81**	**10.96**
4λ	-20.51	10.62

After optimizing the spacing and matching the impedance of feed network, the simulation is done. The return loss of the antenna is found to be -22.8142 dBi and the gain is found 10.964 dBi at 2.45 GHz. The current distributions, RL plot, radiation pattern and polar plot of gain (2D & 3D) are shown below**.**



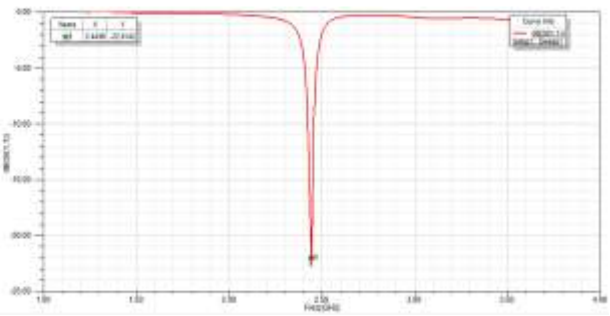


Fig. 9. Current distribution of 1×2 array **Fig. 10.** Return loss of 1×2 array

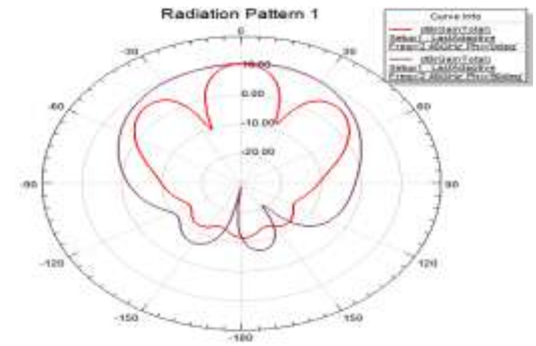


Fig. 11. Radiation pattern of 1×2 array

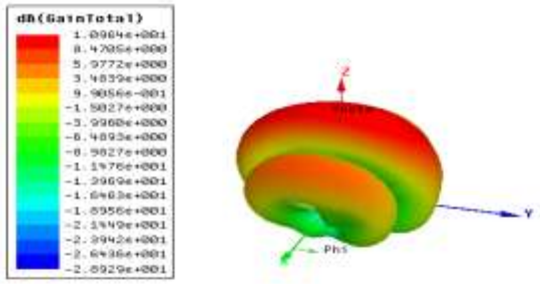


Fig. 12. 3D polar plot of gain of 1×2 array

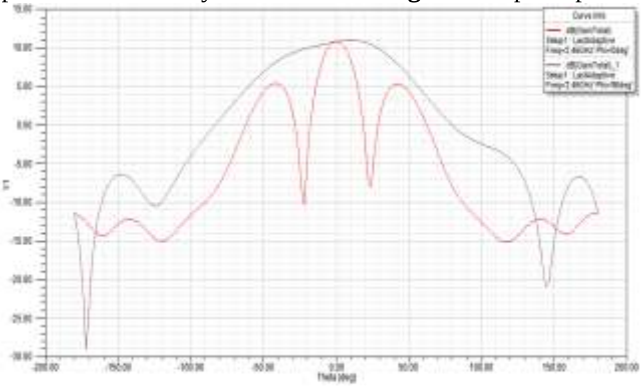


Fig. 13. Gain of 1×2 array at φ=0_deg (E-plane) & 90_deg (H-plane)

1.3 1×4 antenna array Design: A parallel or corporate feed line network issued to build up the antenna array. After simulating the design, we get a Return loss of-14.2000 dBi at 2.45 GHz with an increased gain 14.453 dBi. The current distribution, RL plot, radiation pattern and polar plot of gain (2D & 3D) are shown below.

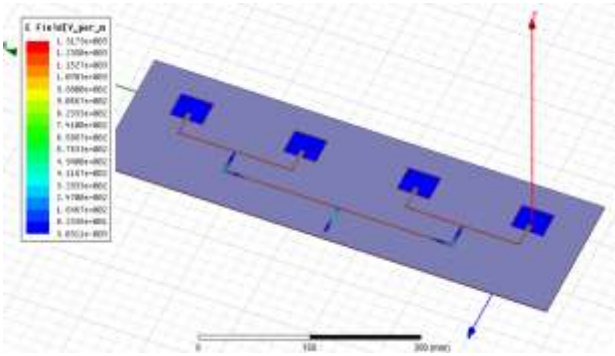


Fig. 14. Current distribution of 1×4 array

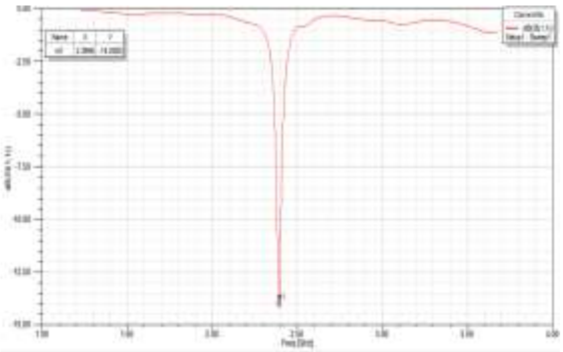


Fig. 15. Return loss of 1×4 array

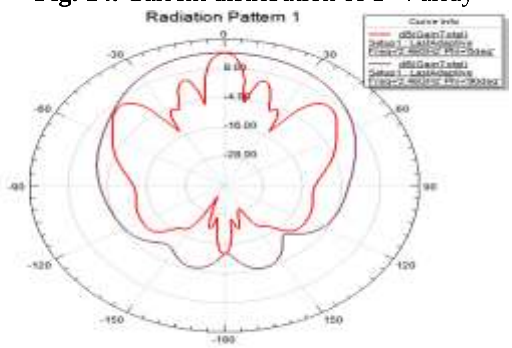


Fig. 16. Radiation pattern of 1×4 array at φ=0_deg (E-plane) &90_deg (H-plane)

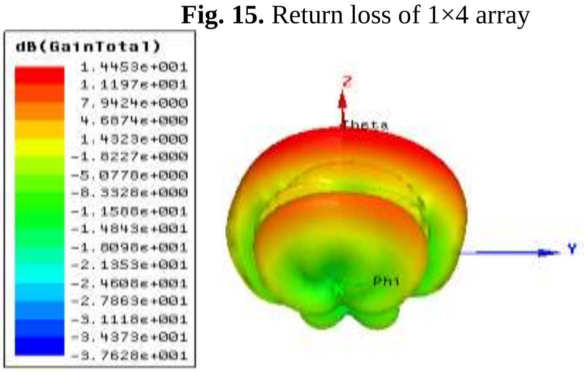


Fig. 17. polar plot of gain of 1×4 array

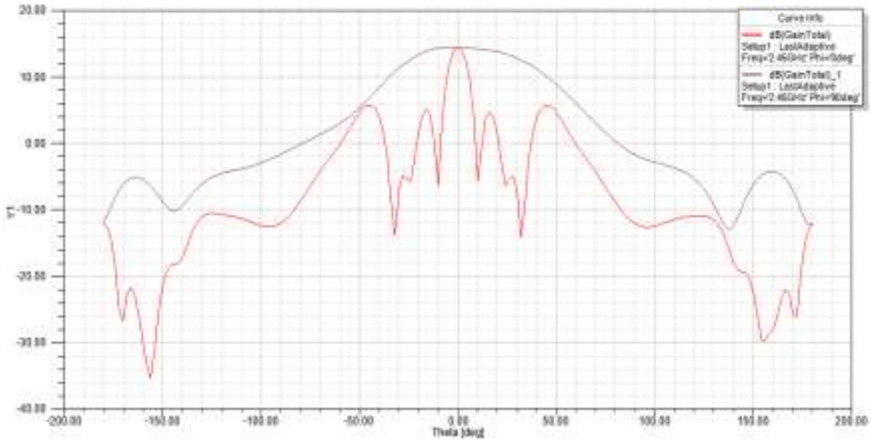


Fig. 18. Gain of 1×4 array at φ=0_deg (E-plane)& 90_deg (H-plane)

III. Comparative Study Of All Antenna Design

After simulating the designs, we got the return loss -23.3579dB and the gain 7.722dBifor single antenna at 2.45 GHz, the return loss -22.8142 dBi and the gain 10.964 dBi were obtained at the same resonant frequency for 1×2 array and finally we got the return loss -14.2000 dBi and an increased gain 14.453 dBi at the same point of frequency. The comparisons with respect to antenna performances are tabulated below:-

Table 3. Comparison between antenna designs

Array elements	**Return Loss** (dBi)	**Gain** (dBi)	**Directivity** (dBi)
1	-23.3579	7.722	7.876
1×2	-22.8142	10.964	11.183
1×4	-14.2000	14.453	14.985

IV. Conclusion

It is seen from above that with increasing the number of elements, gain and directivity of antenna array are improved. The optimization is achieved in 1×2 array for 2_Lambda array element spacing. As a future work, we will make comparison between our proposed design for rectangular patch antenna with different design of triangular or circular patch antennas or other shapes. Different techniques can be invented to provide better radiation efficiency, to reduce of mutual coupling of array element which will make the array more efficient. It would also be possible to design an antenna operating at other frequency bands for using different applications by changing the design parameters.

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