Design of Microstrip Patch Antenna Array for Wireless Applications

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Abstract
The microstrip patch antennas are widely used due to their advantages like planar structure, low profile, ease for manufacturing purpose and cost effectiveness. The performance characteristics of the single microstrip patch antenna can be further enhanced by using microstrip patch antenna array. This paper gives the comparative analysis of improved performance of a 2×2 microstrip patch antenna array as compared to the single microstrip patch antenna for ISM band applications. The operating frequency of the proposed antenna is 2.44 GHz, the substrate used is Rogers RT5880 and simulations are performed in CST Microwave Studio.

Keywords
Microstrip Patch Antenna Array, Microstrip Line Feed, Coaxial Feed, Gain, Directivity, S-Parameter, VSWR, HPBW

I. Introduction

The advancement in the antenna technology in the microstrip patch antenna and its array varies up to wide range of design methodologies and these has also accelerated the development in the modern communication system. The requirements in the modern communication system are low profile, simple planar structure antenna and hence cost-effective to manufacture and these all characteristics are satisfied by the microstrip patch antenna [1]. Hence, microstrip patch antennas are used in the field of cellular communication, satellite communication, airborne and spacecraft applications [2]. The various ways to improve the performance of the microstrip patch antenna is the comparative analysis by changing the shape of the patch, substrate material and using different feeding methodologies. The performance of the microstrip patch antenna can be further enhanced by designing the array structure of the microstrip patch antenna.

The microstrip patch antenna has some of the disadvantages like low efficiency, narrow bandwidth, low power operation and spurious feed radiation [1]. The various ways to improve the bandwidth of the microstrip patch antenna are: (i) increasing thickness of substrate (ii) proper impedance matching (iii) using substrates with less value of effective permittivity iv) by multiple frequency operation [3]. For antennas operating at frequencies less than 10 GHz, the substrates with less thickness and low relative permittivity should be used [4]. For the microstrip patch antenna with thicker substrates when coaxial feed is used, feed length required is more and hence it causes matching problems as it makes the input impedance more inductive [5]. The aperture-coupled feed can be used for more bandwidth requirement. The aperture-coupling when used with crossed slots or off-centred coupling,circular polarization is obtained with more axial bandwidth [6].

The fractal geometry was used in one of the proposed antenna which can be used for multiband applications like Wi-Fi and provides an increase in directivity with reduction in the dimension of the patch [7]. In other proposed antenna, a comparative analysis of dual band dissimilar patch array of two, four, eight and sixteen elements was presented which shows improved performance in terms of gain and bandwidth with increase in array elements [8].

The array of the microstrip patch antenna are used to obtain the radiation pattern that cannot be obtained by single microstrip patch antenna and it also increases the directivity and gain of the antenna [1]. The series feed method when used for array, it has poor directive gain and more return loss but requires less area whereas corporate feed in array provides comparatively high radiation efficiency, low return loss but requires a larger area. The combination of these two feeding method in array is corporate-series feed method which provides moderate return losses and an average area requirement for feeding [4].

In the array of the microstrip patch antenna, the increase in inter-element spacing makes the main lobe in the radiation pattern narrower and increases the number of minor lobes and the position of the main beam can be steered by introducing a phase difference in the input to the array patch elements. The linear microstrip patch antenna array increases gain and directivity but the beam can be steered in only one dimension while planar microstrip patch antenna arrays provides comparatively more directivity and gain than single microstrip patch antenna but less than that of linear arrays but it allows antenna to steer the beam in any direction [9].

The present paper gives the comparative analysis of the performance of the single microstrip patch antenna with a 2×2 microstrip patch antenna array. The feeding method used for the single microstrip patch antenna is coaxial feeding while in the array, the four elements are fed by microstrip line feeding and the entire array is fed by coaxial feeding method.

II. Single Microstrip Patch Antenna

A. Design Procedure

The design methodology used here is the transmission line model of the microstrip patch antenna. The design procedure of the microstrip patch antenna includes the selection of the dielectric material and deciding the height of the dielectric material. In order to get high radiation efficiency and directivity, the relative dielectric constant of the dielectric material, $\epsilon_r \leq 3$. The height of the dielectric material (h) should be $h \leq 1.5$ mm for the antenna having operating frequency less than 10 GHz [4]. So, the dielectric material used is Rogers RT5880 having $\epsilon_r = 2.2$ and its height is taken as 1.5 mm. The height of the dielectric substrate can be selected according to the following formula if the operating frequency (f_r) of the antenna is known [10],

$$h \leq \frac{0.3 v_0}{2\pi f_r \sqrt{\epsilon_r}} \quad (1)$$

where, v_0 is velocity of light in free space.

The schematic diagram of the microstrip patch antenna is as shown in "Fig. 1".The width (W) of the patch can be obtained by using the following equation, [1]

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (2)$$

The fields undergo fringing at the edges of the patch and thus it makes electrical dimensions of the microstrip patch to appear wider as compared to physical dimensions and this is accounted in the resonant frequency in the form of effective dielectric constant $\in_{reff}$ which can be obtained using "(3)".The increase in the electrical length of the patch (ΔL) can be obtained using "(4)" [1].

$$\in_{reff} = \frac{\in_r + 1}{2} + \frac{\in_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (3)$$

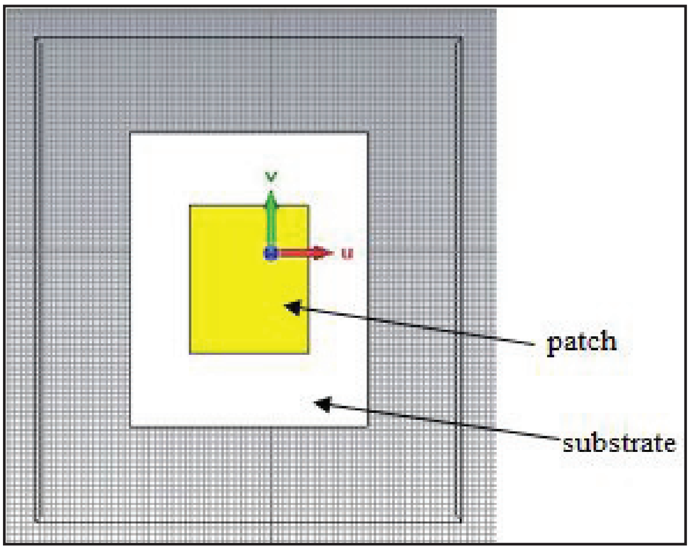

Fig. 1: Schematic of the Single Microstrip Patch Antenna

$$\Delta L = 0.4124h\frac{\left(\in_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\in_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (4)$$

Thus, the effective length of the patch (L_{eff}) and the physical length of the patch (L) can be obtained using "(5)" and "(6)" respectively as, [1]

$$L_{eff} = \frac{v_0}{2f_r\sqrt{\in_{reff}}} = L + 2\Delta L \quad (5)$$

$$L = \frac{v_0}{2f_r\sqrt{\in_{reff}}} - 2\Delta L \quad (6)$$

The dimensions obtained from the above equations were then optimized to obtain the required simulation results. The feeding method used is coaxial feeding.

B. Simulation results

The s-parameter,obtained at 2.44 GHz is -31.0969 dB which is less than -10dB and hence there is proper impedance matching between the feed and the antenna. The Voltage Standing Wave Ratio (VSWR) should be in the range of 1 to 2 and the obtained VSWR is 1.0573. The plot of s-parameter(return loss) versus frequency is shown in "Fig. 2".The radiation pattern obtained is shown in "Fig. 3" which shows that it is directional antenna. The gain and directivity obtained are 8.010 dB and 8.128 dBi respectively. The polar plot of the far-field gain with constant $\boldsymbol{\phi}$-direction is shown in "Fig. 4". The main lobe magnitude in the constant $\boldsymbol{\phi}$-direction is 8.01 dB and it is directed to 1°$\boldsymbol{\theta}$-direction and the side lobe magnitude is -18.5 dB.The Half Power Beam Width (HPBW) obtained is 68.5°. The radiation efficiency (k) was achieved using "(7)" as, [1]

$k = G(\theta, \phi)/D(\theta,\phi)$
$= 0.9731 = -0.1183$ dB or 97.31% (7)

From the obtained results, it can be said that the single microstrip patch antenna designed has optimum radiation efficiency and also the radiation obtained is directional. Now, microstrip patch antenna array is designed and analysed.

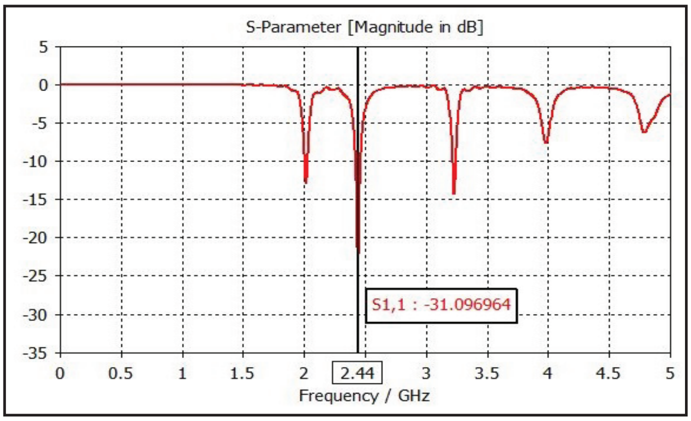

Fig. 2: Plot of Return Loss Versus Frequency

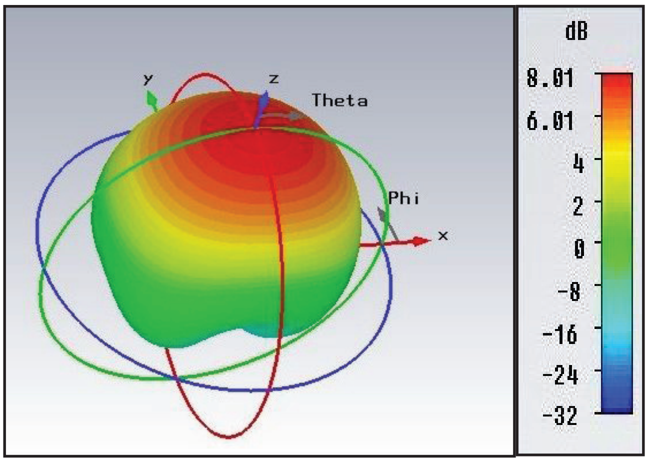

Fig. 3: Far-field Radiation Pattern for Gain (dB)

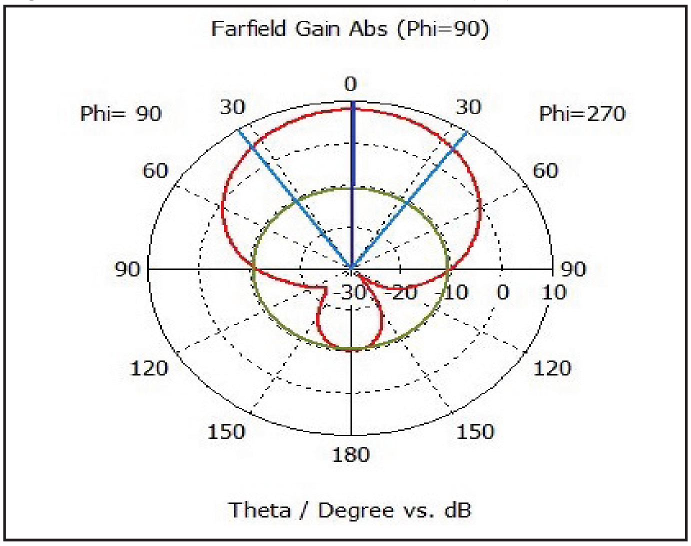

Fig. 4: Polar Plot of Far-Field Gain (Constant $\boldsymbol{\phi}$)

III. Microstrip Patch Antenna Array

A. Design Procedure

The design procedure for 2×2 microstrip patch antenna array is similar to design of the single microstrip patch antenna but here the four patches are fed by microstrip line and the entire antenna is fed by coaxial feeding. The schematic of the proposed microstrip patch antenna array is shown in “Fig. 5”.

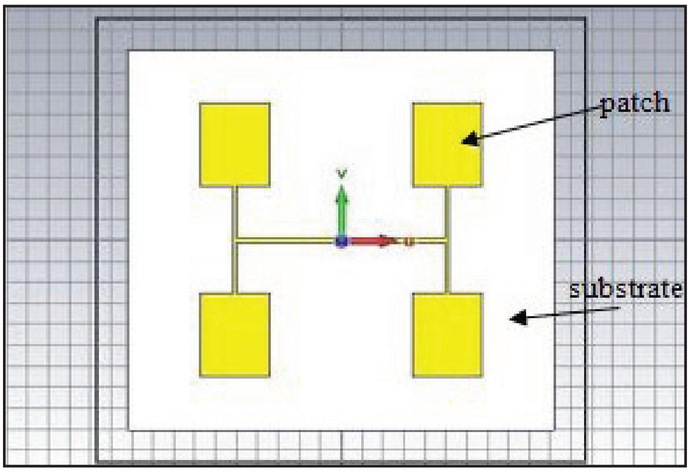

Fig. 5: Schematic of the 2×2 Microstrip Patch Antenna Array

The required simulation results are obtained after optimizing the dimensions of the designed antenna to obtain the required resonant frequency and proper matching of the source to the load impedance.

B. Simulation Results

The s-parameter obtained at 2.44 GHz is -40.4123 dB and the plot of s-parameter versus frequency is shown in “Fig. 6”. The VSWR obtained is 1.0192. The radiation pattern obtained is shown in “Fig. 7”. The gain obtained is 13.38 dB and the directivity obtained is 13.42dBi. The polar plot of the far-field gain is as shown in “Fig. 8” with constant ϕ-direction. The magnitude of the main lobe is 13.5 dB and it is directed towards 43°θ-direction and the magnitude of the side lobe is -7.9 dB. The HPBW obtained is 24.2°. The radiation efficiency (k) was achieved using “(8)” as, [1]

k = G(θ,ϕ)/D(θ,ϕ)
=0.9924 = -0.03310 dB or 99.24% (8)

From the obtained result, it can be said that the designed microstrip patch antenna array has omnidirectional pattern. Also, the radiation efficiency obtained is 99.24% and thus, the radiation efficiency of the microstrip patch antenna array has been improved up to considerable extent as compared to single microstrip patch antenna. Also, other antenna performance parameters are also improved which can be analysed by the comparative analysis of the single microstrip patch antenna and its array. The substrate material used in both the cases is Rogers RT5880.

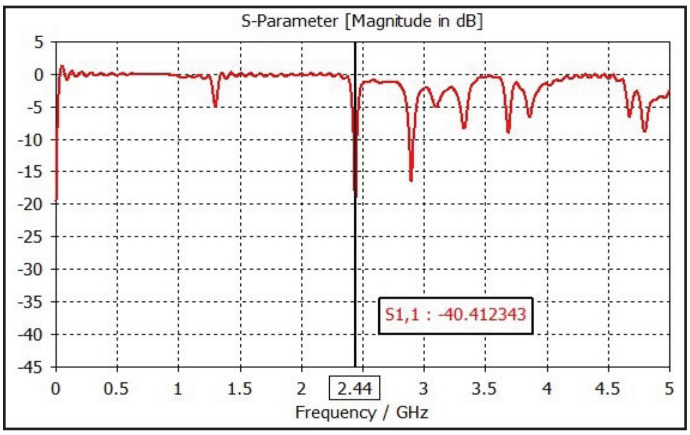

Fig. 6: Plot of Return Loss Versus Frequency (Array)

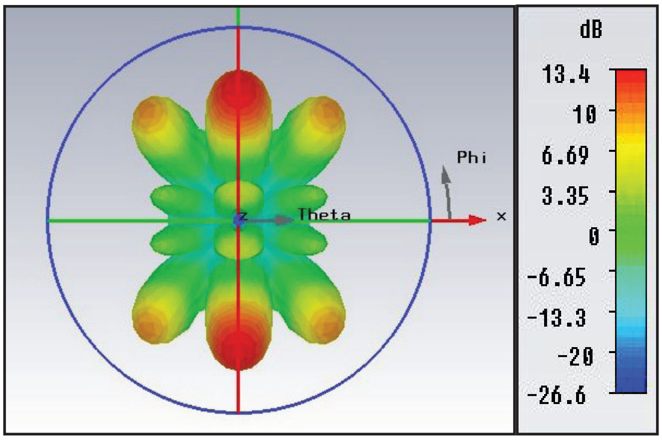

Fig. 7: Far-Field Radiation Pattern for Gain (dB) (Array)

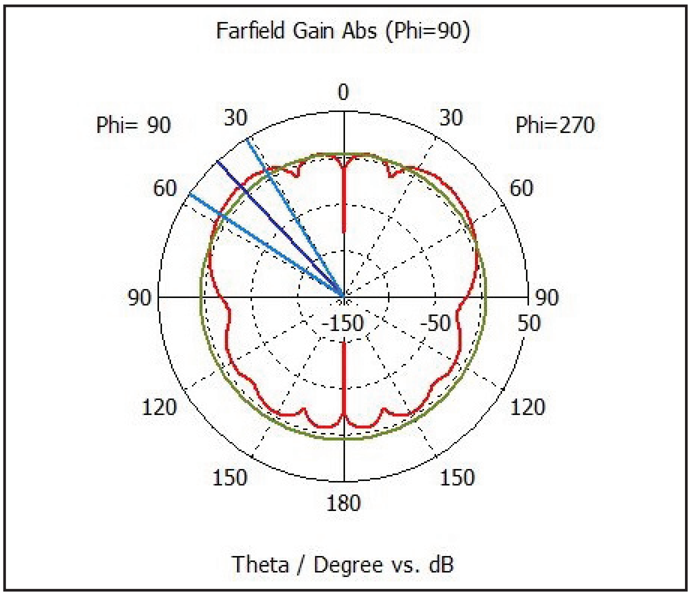

Fig. 8: Polar Plot of Far-Field Gain (Constant ϕ) (array)

IV. Comparison of the Performance of The single Microstrip Patch Antenna and its Array

The performance between the single microstrip patch antenna and the 2×2 microstrip patch array is shown in “Table 1”. The obtained results shows that gain, directivity, s-parameter, VSWR, HPBW and radiation efficiency of the 2×2 microstrip patch array is improved as compared to the single microstrip patch antenna.

Table 1: Comparison of Performance

Parameters	Single microstrip patch antenna	2×2 microstrip patch antenna array
s-parameter	-31.0969 dB	-40.4123 dB
VSWR	1.0573	1.0192
Gain	8.010 dB	13.38 dB
Directivity	8.128 dBi	13.42 dBi
HPBW	68.5°	24.2°
Radiation efficiency	97.31%	99.24%

V. Conclusion

The result analysis of the proposed single microstrip patch antenna and 2×2 microstrip patch antenna array is undertaken. These results shows that the antenna performance of the array is improved in terms of gain, directivity, HPBW, s-parameter, VSWR and the radiation efficiency for the resonating frequency of 2.44 GHz as compared to the single microstrip patch antenna.

This type of antennas can be used for wireless applications in which the ISM frequency band is used like for Wi-Fi and WiMAX applications.

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