Design and Implementation of Microstrip patch Antenna Arrays for 2.4 GHz Applications

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Design and Implementation of Microstrip patch Antenna Arrays for 2.4 GHz Applications

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Abstract
The main objective of the paper is to design and implement the microstrip antenna arrays for 2.4 GHz applications. Initially we design and implement single element antenna and analyse outcomes of its features such as operating frequency, return loss, gain, VSWR and radiation patterns. Later the single element is converted to 2x1 patch antenna array. Finally to increase gain, bandwidth and to have better radiation patterns it is transformed to 4x1 patch antenna array. The detailed procedure of design and obtained results of single component, 2x1 microstrip patch antenna array and 4x1 microstrip patch antenna array are discussed. The FR4 substrate material was used in our design and to fabricate the prototype of the antenna. The obtained result of both simulated and measured indicates that they are comparable with one another.

Keywords: Microstrip patch antenna, 2x1 patch antenna array, 4x1 patch antenna array, 2.4 GHz.

1 Introduction

Microstrip antennas are preferred and used in various wireless communication devices because of their lightweight, low volume, small profile configuration and a low fabrication cost.

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Each one of the antenna is best known for their own nature of characteristics, design implementations and applications. The existing days are cannot be imagined without technology and microstrip antennas are backbone and strength of various wireless communication applications. The
microstrip antennas play very vital role in wireless communication technologies in the recent scenarios [1]. The microstrip antennas without any kind of difficulty can be mounted on several wireless communication devices, rockets, missiles, satellites without any major modification and very easily array structures can be designed from the microstrip antennas [2].

The rectangular microstrip patch antenna configurations are frequently used as compared to other types like circular, triangular, hexagon etc. For simple and the most challenging applications we prefer the microstrip patch antennas. Dual frequency operation, Dual characteristics, frequency agility, circular polarizations, broad bandwidth, beam scanning and feed line flexibility can be achieved easily from these microstrip patch antennas [3]. Furthermore to design miniature systems using in telecommunication systems several small antenna designs described in literature. Planar antennas are preferably used in mobile systems [4]. The various different frequency ranges are used for wireless communication [5-6]. For our proposed we select 2.4 GHz ISM frequency. We feed the microstrip patch antenna arrays through a microstrip line feed and investigate the operating frequency, return loss, gain, VSWR and radiation patterns at 2.4 GHz operating frequency.

M. T. Islam et al. designed a 150 mm X 150 mm size microstrip antenna by using novel U-shaped feeding strip working on together at 2.45/5.8 GHz. Maximum gain of 9.56dBi and 10.17dBi for both bands with steady radiation patterns [7]. T. S. Ooi et al. designed miniature 60 mm X 60 mm dual band circular polarized antenna operating at 2.45/5.8 GHz. The design consists of two FR4 patches. The two different square patches are corner truncated and stacking has been done in a dielectric substrate layer, the designed microstrip exhibits circular polarization for both frequencies and obtained measured return loss achieved are -11.5 dB and -12.8 dB for 2.45 GHz and 5.8 GHz. They obtained gain of 7.34 dB and 12.8 dB [8].

Lin Peng et al. designed asymmetric M-shaped patch antenna of size 64 mm X 62 mm for 2.45/5.8 GHz. They obtained return loss of -15 dB and gain 6.32 dB for 5.77 GHz [9]. Pingan Liu et al. designed compact CPW-fed tri-band printed antenna of size 23 mm X 36.5 mm using FR4 operating at 2.4/5.8 GHz. The designed consist of Y-shaped patches with different dimensions and obtained gain of 2.5 dB and return loss of -15 dB for 5.8 GHz [10]. Qurratul Ayn et al. designed improved gain 2x1 Circular Patch and 4x1 Circular Patch Antenna Arrays for 2.4 GHz Applications using FR4 material and excited using probe feed and edge feed technique and achieved return loss values -12.17 dB and -22.87 dB and gain 5.74 dB and 8.25 dB [11]. Wen-Shan Chen et al. designed 2 2 microstrip antenna array for 5G C-band 3.5 GHz using microstrip line feeding technique and achieved return loss below -10 dB and gain 5.37 dB [12].
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[13]. A.R.G.Chandra et al. designed Triangular and Rectangular Microstrip Antenna Arrays at a resonant frequency of 2.2GHz obtained return loss value is up to -32 dB and the maximum gain up to 7 dB [14]. Jagtar Singh Sivia et al. designed 1x2 and 1x4 patch antenna array using series feed network for S, C and X-band obtained return loss value up to -28 dB for frequency range and achieved the gain up to 9.93 dB [15]. An antenna can be feed through many techniques. Major techniques are microstrip planar feed, coaxial feed, aperture coupled microstrip feed and proximity coupled microstrip feed [16]. The microstrip transmission line is the best and easy method by which antenna is excited [17]. Easy modelling are the benefits and increased thickness of substrate are the drawbacks due to this method bandwidth is narrow [18].

2 Antenna design

2.1 Construction of single element antenna

The substrate material FR4 was used in the design. The substrate material with dielectric constant 4.4, loss tangent 0.0245 and height 1.6 mm was considered for our design. The optimization of newly designed antenna has been done by 3DEM of Mentor graphics software tool.

The rectangular patch width and length is calculated using the formula

The designed patch width is calculated using the equation

\[ W = \frac{c}{2 \pi f} \sqrt{\frac{2}{\epsilon_r + 1}} \]  

(1)

The designed patch Length is calculated using the equation

\[ L_p = L_{eff} - 2 \Delta L \]  

(2)

The Extension Length of the Patch is calculated as

\[ \Delta L = 0.412 \frac{\left( \varepsilon_{reff} + 0.3 \right) \left( w + 0.264 \right)}{\left( \varepsilon_{reff} - 0.258 \right) \left( h + 0.8 \right)} \]  

(3)

The relation between actual length and effective length of designed patch is given by

\[ L_{eff} = L + 2 \Delta L \]  

(4)

The effective length of patch is given by

\[ L_{eff} = \frac{\lambda_g}{2} \]  

(5)

We kept the inter element spacing to be 62.85 mm for the 2x1 and 4x1 patch antenna arrays.

Further, we also calculated the operating frequency, return loss, gain,
VSWR and radiation patterns for single microstrip patch antenna. Then we further extended the work to calculate the above mentioned parameters to 2x1 antenna array and 4x1 antenna array by using 3DEM of Mentorgraphics software.

Fig. 1. Shows the geometry of single element rectangular microstrip patch antenna operating at 2.4 GHz frequency.

2.2 Construction of two (1x2) and four (1x4) element rectangular microstrip array antenna

Fig. 2. shows the proposed two (1x2) and four (1x4) rectangular microstrip array antenna. The same relative permittivity is used to design and fabricate two (1x2) and four (1x4) array antenna as that of used for single element antenna [19]. The designed linear array antenna uses equal spacing between each rectangular patch array element [20, 21]. The all dimensions of the proposed designs are shown in Table 1.

Fig. 1 Single element rectangular microstrip patch antenna

In the proposed work microstripline feeding network is used for two (1x2) and four (1x4) element array antenna with three different widths of microstrip lines i.e., 100 JΩ, 70.7 JΩ and 50 JΩ are used. The array elements are feeded in parallel to a source of feeding network. The designed corporate feeding network uses wilkinson power divider methodology which divides the power in equal proportional ratio and the microstrip feed lines used in power divider of two element (1x2), four (1x4) array antenna is equivalent to resistor which is in between the two output ports.

3 Simulated and Measured Results

The single element, two (1x2) array and four (1x4) array antennas with microstrip line feeding technique were designed by using 3DEM of mentorgraphics software. Later designed single element, two (1x2) array and four (1x4) array antennas are fabricated and tested by using network analyser.

The fabricated antennas are shown in Fig. 2. The operating frequency, return loss, gain, VSWR and radiation patterns of single element, two (1x2) and four (1x4) elements are displayed. The
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measured and simulated results of proposed array antenna return loss are compared and presented in Fig. 3.

![Figure 2](image1.png)

**Fig. 2** (a) Two (1x2) array antenna simulated model (b) Two (1x2) array antenna fabricated model (c) Four (1x4) array antenna simulated model (d) Two (1x4) array antenna fabricated model

In the Fig. 3(a), the simulated value of return loss of single element microstrip patch antenna is -40.5 dB and the measured is -15.7 dB at 2.4 GHz. Fig. 3(b) shows the simulated and measured results of two (1x2) element array antenna as -28.5 dB and -32 dB at 2.4 GHz. In Fig. 3(c) the four (1x4) element array antenna simulated and measured return loss are -27.7 dB and -23.8 dB at 2.4 GHz.

![Figure 3](image2.png)

The Fig. 4(a) shows simulated and measured gain of single element antenna as 1.87 dB and 1.60 dB at 2.4 GHz. Fig. 4(b) shows simulated and measured gain of two (1x2) element array antenna as 4.04 dB and 3.75 dB at 2.4 GHz. Fig. 4(c) shows simulated and measured gain of four (1x4)
element array antenna as 6.28 dB and 5.82 dB at 2.4 GHz.

Table 1 Single, Two (1×2) and Four (1×4) element patch parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of each patch</td>
<td>38.03 mm x 29.44 mm</td>
</tr>
<tr>
<td>Spacing between patches</td>
<td>62.85 mm</td>
</tr>
<tr>
<td>100Ω feedline width</td>
<td>0.7 mm</td>
</tr>
<tr>
<td>70.7Ω feedline width</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>50Ω feedline width</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

Fig. 5(a) shows simulated and measured VSWR (Voltage Standing Wave Ratio) of single element antenna as 1.03 and 1.05 at 2.4 GHz. Fig. 5(b) shows simulated and measured VSWR of two (1×2) element array antenna as 1.08 and 1.15 at 2.4 GHz. Fig. 5(c) shows simulated and measured VSWR of four (1x4) element array antenna as 1.09 and 1.21 at 2.4 GHz.

Fig. 6(a) and Fig. 6(b) shows the radiation patterns of single element rectangular patch antenna in E-Plane and H-Plane at 2.4 GHz. This indicates that the measured results agree satisfactorily with the simulations. The antenna displays broad linear polarization beamwidth at required frequency 2.4 GHz. The antenna half-power beamwidths have been observed to be 102.39° and 101.46° in E-plane and H-plane at 2.4 GHz, respectively.

Fig. 6(c) and Fig. 6(d) shows the radiation patterns of two (1x2) element patch antenna array in E-Plane and H-Plane at 2.4 GHz. The antenna half-power beamwidths have been observed to be 77.95° and 28.40° in E-plane and H-plane at 2.4 GHz, respectively. Fig. 6(e) and Fig. 6(f) shows the radiation patterns of four (1x4) element patch antenna array in E-Plane and H-Plane at 2.4 GHz. The antenna half-power beamwidths have been observed to be 159.62° and 24.86° in E-plane and H-plane at 2.4 GHz, respectively.

4 Comparisons of Three Models

Table 2 shows the comparisons between the single element, two (1×2) element array and four (1×4) element array antennas.

5 Results and Discussions

Three model’s single element two (1×2) and four (1×4) linear rectangular microstrip array antennas are designed, simulated and measured at a operating frequency 2.4 GHz of ISM band applications using microstrip line feeding technique.

The fabricated array antennas are explained and parameters like operating frequency, return loss, gain, VSWR and radiation patterns are plotted. By comparing the results of a single element and array element plots,
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we can ensure, with increasing elements the enhancement of return loss, gain, VSWR and radiation patterns performance is done and the proposed antennas potentially serves as a best option for short range 2.4 GHz of ISM band wireless communication applications.

(a)

(b)
Fig. 3 (a) Single element Return Loss (b) Two ($1\times2$) element Return Loss (c) Four ($1\times4$) element Return Loss.
Fig. 4 (a) Single element gain (b) Two (1x2) element gain (c) Four (1x4) element gain
**Fig. 5** (a) Single element VSWR (b) Two (1x2) element VSWR (c) Four (1x4) element VSWR
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(b)

(c)

(d)
Fig. 6 (a) Single element radiation pattern E-Plane (b) Single element radiation pattern H-Plane (c) Two (1x2) element radiation pattern E-Plane (d) Two (1x2) element radiation pattern H-Plane (e) Four (1x4) element Radiation pattern E-Plane (f) Four (1x4) element radiation pattern H-Plane
Table 2 Parameter comparisons of both simulated and measured Results of different proposed antenna

<table>
<thead>
<tr>
<th>Type of Antenna</th>
<th>Model</th>
<th>Return Loss S11 (dB)</th>
<th>Bandwidth (MHz)</th>
<th>Gain (dB)</th>
<th>VSWR</th>
<th>Half-Power Beamwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Element</td>
<td>Simulated</td>
<td>-40.5 dB</td>
<td>64.58</td>
<td>1.87</td>
<td>1.03</td>
<td>101.48°</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
<td>-15.7 dB</td>
<td>62</td>
<td>1.60</td>
<td>1.05</td>
<td>121.54°</td>
</tr>
<tr>
<td>Two (1x2) antenna array</td>
<td>Simulated</td>
<td>-28.5 dB</td>
<td>80.1</td>
<td>4.04</td>
<td>1.08</td>
<td>73.14°</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
<td>-32</td>
<td>82</td>
<td>3.75</td>
<td>1.15</td>
<td>82.40°</td>
</tr>
<tr>
<td>Four (1x4) antenna array</td>
<td>Simulated</td>
<td>-27.7 dB</td>
<td>103</td>
<td>6.28</td>
<td>1.09</td>
<td>40.33°</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
<td>-23.8</td>
<td>110</td>
<td>5.82</td>
<td>1.21</td>
<td>45.35°</td>
</tr>
</tbody>
</table>

6 Conclusion

The rectangular single Patch, 2x1 antenna arrays and 4x1 antenna arrays were designed and implemented successfully by using the FR4 dielectric material. In the proposed work, microstripline feeding technique used for the simulation of single rectangular element, 2x1 array and 4x1 array. From the proposed design for single patch, 2x1 patch antenna array, 4x1 antenna array experimental validations shows that simulated results were found to be comparable with measured results. It was observed that the antenna resonated at 2.4 GHz and results of return loss, gain, bandwidth, VSWR and Half-Power Beamwidth achieved are satisfactory. The designed microstrip array antennas can be used in short range and low-power telecommunications such as Bluetooth, WiFi, Wireless telephones, Zigbee, NFC and RFID.

References


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