Proposed P-shaped Microstrip Antenna Array for Wireless Communication Applications

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Abstract
In this paper a P-shaped microstrip antenna array is proposed for X-band applications in the frequency range (8.1567-9.3811) GHz. The gain obtained in this frequency range is about 8.305 dBi. The reflection coefficient is less than -10 dB in the above frequency range. The simulation results were obtained for the optimum parameters using the CST software while the practical test was carried out using Vector Network Analyzer (VNA). The microstrip antenna was manufactured using FR-4 substrate with relative dielectric constant of 4.3 and loss tangent \( \tan \delta = 0.002 \). The simulation and practical results were compared. The size of the antenna array is \((33 \times 70 \times 1.6)\) mm\(^3\). This array is suitable for satellite communication, radar application.

Keywords: UWB, microstrip antenna array, reflection coefficient, gain, radiation pattern.

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1. Introduction
In the recent year, ultra wide-band (UWB) technology was unfolded growth experience. The two serious merit of UWB technology are low power and high data rate by transmitting extremely short pulses and spread over the bandwidth and receive it short accurate and efficient pulses [1, 2].

FCC (federal communication commission) give UWB technology industrial attention and attracted academia in wireless world it allowed wide unlicensed band about 7.5 GHz from (3.1-10.6) GHz with ERIP (Effective Isotropic Radiated Power) less than -41.3 dBm/MHz for communication application like imaging radar, remote sensing and localization application [3, 4]. Now adays, microstrip antenna plays an important role because of its light weight low cost planar fabricated and non-planar surface, when it is mounted on rigid surface has robust flexibility. However, microstrip antenna also has some disadvantages, low gain, narrow bandwidth, unacceptable efficiency [5-8].

Microstrip antenna array was used to enhance the performance of single element microstrip antenna. The efficiency and distribution voltage depend on feeding technique, when voltage induced in one point in feed that is suitable feed network [9]. Two feed technique are used in microstrip antenna array that responsible for improving antenna performance there are corporate feed network and series feed network. The corporate feed has high gain over frequency band that made broadside beam antenna with main drawback is rareness efficiency because of complicated and long feeding antenna [6, 7, 9-11]. The series feed network, despite of simple and compact arrangement feed method but it has lower gain compared with corporate feed [6, 9]. To propose antenna array is worked within X-band location for wireless communication application especially for military application. Microstrip array antenna with corporate center feed was suggested and parametric study was investigated.

2. Single P-shaped Antenna
The single antenna structure for UWB is shown Figure 1. It was designed by FR-4 substrate with \( \varepsilon_r = 4.3 \) and height \( h=1.6\)mm and loss tangent \( \tan\delta=0.002 \). The optimum parameters were listed in Table 1.
Table 1. Antenna Parameters Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Ls</td>
<td>33mm</td>
<td>X1</td>
<td>2</td>
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<tr>
<td>Ws</td>
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<td>X2</td>
<td>2.8</td>
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<tr>
<td>Lg</td>
<td>10</td>
<td>X3</td>
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<tr>
<td>Wg</td>
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<td>X4</td>
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<td>18</td>
<td>X5</td>
<td>2.8</td>
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<tr>
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<td>1.4</td>
<td>Y</td>
<td>4.5</td>
</tr>
<tr>
<td>R1</td>
<td>4.7</td>
<td>Z</td>
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<tr>
<td>R2</td>
<td>4.4</td>
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However, Figure 2 shows the practical result for reflection coefficient $S_{11}$; it was observed that the resultant bands is (5.75-7.74) GHz, (9.645-11.925) GHz in which $S_{11} < -10dB$. The maximum gain is (4.947) dBi as shown in Figure 3. Therefore, a 2-element array antenna was proposed to improve the gain of such antenna.
3. P-shaped UWB Antenna Array

2-element antenna array was designed in corporate feed structure with P-shaped patch are placed on each side of FR-4 substrate that has dimension (33×70) mm² with dielectric constant $\varepsilon_r=4.3$ and height $h=1.6$mm with optimum distance between elements $X=38$ mm as shown in Figure 4. Now let us investigate the parametric study as follows.

![Figure 4. P-shape antenna array](image)

3.1. Effect of Center Feed Length

Figure 5 (a) shows 2-elements P-shaped antenna array, and Figure 5 (b) shows $S_{11}$ vs. frequency for changing the length of the center feed. It noted that $Y_1=10$ mm give good band width (i.e. $S_{11} < -10$ dB).

![Figure 5. Effect of center feed length](image)

3.2. Effect of Center Feed Width

Figure 6 (a) shows 2-elements P-shaped antenna array, and Figure 6 (b) shows $S_{11}$ vs. frequency for changing the width of center feed, it is observed that $n=0.65$ mm give good band width (i.e. $S_{11} < -10$ dB ).

![Figure 6. Effect of center feed width](image)
3.3. Effect of Horizontal Combination Feed Width

Figure 7 shows (a) 2-elements P-shaped antenna array, and (b) shows $S_{11}$ vs. frequency for changing the width of horizontal combination feed, it is clear that $Y_2=0.65$ mm give good band width with (i.e. $S_{11} < -10$ dB).

![Figure 7. Effect of horizontal combination feed width](image)

3.4. Effect of Elements’ Feed Width

Figure 8 shows $S_{11}$ vs. frequency for changing the width of elements feed, it is noted that $w_f=1.4$ mm give good band width (i.e. $S_{11} < -10$ dB).

![Figure 8. Effect of elements’ feed width](image)

3.5. Effect of Ground Length

Figures 9 (a-b) shows $S_{11}$ vs. frequency for changing the length of ground, it is seen that $L_g=10$ mm give good band width (i.e. $S_{11} < -10$ dB).

![Figure 9. Effect of ground length](image)
3.6. Effect of Etching Slots in Ground

The response of the antenna array was enhanced by etching slots in ground plane as shown in Figure 10 and Figure 11 respectively. Two stair slots are etched at the each sides of ground in the beginning with length $X_1=8$ mm and width of steps $X_2=1$ mm with space between steps $S=1.75$ mm, than etched two rectangular slots on each side of feeder in ground side with dimension $(bt=1 \times ht=10)$ mm$^2$, these changes in ground give quad bands, the first band (8.163-9.379) GHz, second band (11.279-11.526) GHz, (14.49-14.87) GHz and (16.276-16.58) GHz as shown in Figure 12.

![Figure 10. Stair slot in ground plane of 2-element p-shaped antenna array](image)

![Figure 11. Stair slot and rectangular on each side of ground plane of 2-element P-shaped antenna array](image)

![Figure 12. Effect of etching slots in ground](image)

The optimum parameters of the modified antenna array are listed in Table 2. However Figure 13 shows the photograph of the fabricated antenna array using PCB process. Figure 14 shows the comparison between the simulation results and practical results for return loss $S_{11}$.

![Table 2. P-shaped Antenna Array Parameters](image)

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Figure 13. Practical 2-element P-shaped antenna array (a) top view (b) bottom view

Figure 14. Comparison the measured results and simulated results $S_{11}$ vs. frequency curve

Figure 14 shows a reasonable agreement between the simulation and tested results with some shift between bands that is because of the unspecific values of $\varepsilon_r$ and possible fabrication error. Also, there is a slight difference concerning the band bandwidth due to the SMA connector’s loss.

The simulation antenna arrays offer good matching for frequencies covering (8.1567-9.3811) GHz, with reflection coefficient of about (-41.553) dB at frequency of (8.429) GHz, also it covers another band (11.279-11.359) GHz, (14.482-14.877) GHz and(16.275-16.593) GHz while the fabrication antenna offers good matching operation for frequencies covering (8.035-8.945) GHz, with reflection coefficient of (-29.778) dB at frequency of (8.425) GHz also offer good matching at bands (10.18-10.33) GHz, (11.285-12.065) GHz, (13.43-14.21), (17.07-18.5) GHz. The gain of the modified antenna array is (5.635-8.305) dBi as shown in Figure 15.
4. Current Distribution and Radiation Patterns

To clarify details about the properties of proposed antenna array, some frequencies are chosen to illustrate the current distribution and radiation patterns. The current distributions of proposed antenna array are shown in Figure 16 at frequencies (8.41, 9.132, 9.248, 11.412, 14.68, and 16.428) GHz respectively and they illustrate maximum currents are generated on antenna array surface. Also the 3D farfield radiation patterns for proposed antenna array has maximum directivities (8.37, 7.16, 7.05, 7.73, 8.01 and 5.83) dBi respectively as shown in Figure 17. The radiation patterns for the proposed antenna array are illustrated in Figure 18 in E-plane and H-plane for previous frequencies. From these figures, it's noted that, bi-directional patterns are radiated form this array antenna.

![Current Distributions and Radiation Patterns](image)

Figure 16. The current distributions of the antenna array for frequencies
(a) 8.41 GHz (b) 9.132 GHz (c) 9.248 GHz (d) 11.412 GHz (e) 14.68 GHz (f) 16.428 GHz
Figure 17. 3D farfield radiation patterns for frequencies 
(a) 8.41 GHz (b) 9.132 GHz (c) 9.248 GHz (d) 11.412 GHz (e) 14.68 GHz (f) 16.428 GHz
Figure 18. Simulated-radiation patterns for P-shaped antenna array for frequencies
(a) 8.41 GHz (b) 9.132 GHz (c) 9.284 GHz
Figure 18. Simulated-radiation patterns for P-shaped antenna array for frequencies (d) 11.412 GHz (e) 14.68 GHz (f) 16.428 GHz

5. Conclusion
A P-shaped antenna for wireless communication is proposed and then an array is implemented. However the single P-shaped characteristics were investigated and then the 2-element P-shaped antenna is proposed and modified to enhance the gain. Also it was found
that etching slots in the ground plane results in more operating bands in which $S_{11} < -10\text{dB}$ which indicates the suitability of using the P-shaped antenna for many wireless communication proposes (i.e. satellite communication and military application). However the array is fabricated and tested using the VNA device. The size of the antenna array is $(33 \times 70 \times 1.6) \text{mm}^3$, with FR-4 substrate. It was noted that there is reasonable agreement between simulation results and tested results. We believe that, the main reason for the error is the unspecific value of $\varepsilon_r$ and due to fabrication error.

References