Sustainable Design of Multiband Antenna for Wireless Communication Applications

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Abstract. This work emphasises sustainability as a crucial component of the design process and offers a novel approach to antenna design. A miniature circular microstrip antenna array with 1800 hybrid coupler operating at different modes of frequency, specifically aiming for multiband wireless communication is presented. The Circular patch, two element broad side array and end fire array structures are designed and analysed by using High Frequency Software Simulator (HFSS) software. Measured results are also presented for validating the simulated results.

1 Introduction

Microstrip patch antenna is basically a single layer design, with four parts of the design namely, substrate, patch, feedline, and ground plane [1]. Microstrip antenna is find applications at frequencies from 1 to 100 GHz. Based on research below UHF frequencies microstrip antennas are best suggestable in the place of conventional antennas. Based on research the micro strip antennas replace conventional antennas for various applications purposes [2]. A single multiband antenna is designed to operate a single antenna in multiple bands of frequencies i.e., for multiple applications [3, 4]. A multiple frequency band antenna is designed in such a way that one part of the antenna is active for one band while another part is active for a different band [5]. A multiband antenna made of a single antenna has good directivity but sometimes fails to transmit the signal to the receiver without losses [6-8]. So, we use an antenna array. Antenna array is a structure arranged such that directional properties are added up in the desired direction [9, 10]. Primarily the advantages of the microstrip antennas are compact size, low profile, and less weight, conformable to planar and non-planar surfaces.

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It occupies a very little volume of the structure in installation and is very applicable for multiband wireless communications [11,12] along with image processing applications [13-30].

2 Design Methodology

A circular microstrip patch antenna is designed at 5GHz with FR4 substrate with height 1.6mm, the designed antenna is simulated and results are presented. A simple circular patch antenna is depicted in Figure 1. Design equations of circular microstrip patch antenna are as given in Eq(1) & (2). Where, a is radius of circular microstrip patch antenna, f_r is the resonant frequency, h is the height of the radiating patch, \( \varepsilon_r \) is the permittivity of dielectric constant. Broad-side array is an arrangement where the principal direction of the radiation is perpendicular to the array axis and also to the plane containing the array element. Therefore, the radiation pattern of the antenna is said to be perpendicular to the axis on which the array exists. The End-Fire structure is quite similar to the broadside array structure from view of arrangement. But the main difference is the direction of the maximum radiation. For the end fire array the radiation maxima is along the axis of the array.

![A tilted circular microstrip patch antenna](image)

Fig.1. Schematic diagram of basic circular patch antenna

\[
\begin{align}
\alpha &= \sqrt{\frac{F}{\pi}} \sqrt{\frac{1+\frac{2h}{\varepsilon_r}}{\pi \varepsilon_r}} \left( \sin \left( \frac{\pi F}{2h} \right) + 1.7726 \right) \\
F &= \frac{8.971 \times 10^8}{f_r \sqrt{\varepsilon_r}} F = \frac{8.971 \times 10^8}{f_r \sqrt{\varepsilon_r}}
\end{align}
\]

3 Design Specifications

A circular microstrip patch antenna, two elements Broadside array antenna and two element End fire array are designed at 5 GHz with substrate height 1.6mm and permittivity 4.4. Feed networks are designed for all the three structures for required phase shift. For a single circular patch antenna a simple 50 ohms feed line is incorporated. A “T” shaped 3dB power divider is augmented for the broad side array to obtain the pattern perpendicular to the axis of the array. For end fire array 180 hybrid coupler with 3dB power division is accomplished to achieve radiation maxima along the axis of the antenna array. The design parameters at 5 GHz are given in Table 1.
Table 1: Design Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>5GHz</td>
</tr>
<tr>
<td>Gain</td>
<td>5 dB</td>
</tr>
<tr>
<td>Band width</td>
<td>Multiband frequencies</td>
</tr>
<tr>
<td>$S_{11}$</td>
<td>$&lt;$15dB</td>
</tr>
<tr>
<td>RF range</td>
<td>L band, S band, C band</td>
</tr>
<tr>
<td>Circular patch radius</td>
<td>34 mm</td>
</tr>
<tr>
<td>Substrate material, thickness, permittivity</td>
<td>FR4 epoxy, 1.6 mm, 4.4</td>
</tr>
</tbody>
</table>

4 Simulated Antenna structures

Fig. 2. Single patch microstrip antenna.  
Fig. 3. Broad side array antenna.  
Fig. 4. End fire array antenna-180 degree hybrid coupler with 4 ports and impedance matching line

Simulated structures of single circular patch antenna and two element broadside array antenna with “T” shaped 3 dB power divider are shown in the Figures of 2, 3 and 4 respectively.

5 Results and Discussions

The mentioned microstrip antenna designs i.e., a single patch microstrip antenna, broadside array antenna, end fire array-180-degree hybrid coupler are designed and analysed using High frequency software simulator (HFSS) software at resonant frequency of 5GHz. Antennas are being analysed by various parameters like return loss, gain and current density pattern for multiband applications.
In a single circular patch antenna, 8 multi bands are obtained and the characteristic graphs are presented below. $S_{11}$ obtained are -21 dB, -14.5 dB, -20 dB, -33 dB, -26 dB, -13.5 dB, -22 dB, -18 dB, at frequency 2.8 GHz, 3.6 GHz, 4.4 GHz, 5.2 GHz, 5.5 GHz, 6.2 GHz, 7 GHz, 8 GHz respectively as shown in Figure 5. The obtained Gain for the single element antenna is -14.45 dB as shown in Figure 6. Figure 7 represents the current distribution circular patch element at different phases 0°, 90°, 180° respectively.

The $S_{11}$ vs frequency plots are depicted in Figure 8 for the proposed broadside array. There is a slight shift in the maximum direction. The gain plot at 5 GHz is shown in Figure 9. For broadside array antenna from the Figure 8, eleven bands are attained with $S_{11}$ values obtained -21 dB, -17 dB, -18 dB, -12 dB, -12 dB, -23 dB, -18 dB, -28 dB, -14 dB, -13 dB, -11 dB at frequency of 1.2 GHz, 2.1 GHz, 4 GHz, 4.5 GHz, 5.5 GHz, 5.7 GHz, 6.3 GHz, 7.5 GHz, 9.3 GHz, 11 GHz, 13 GHz respectively. Gain obtained for the same broad side antenna array is 9.3 dBi.
Current distribution at different phases is represented in Figure 10.

Figure 13 shows the current distribution at different phases. Red color represents higher radiation along the edges of the patch. The Blue color represents the less current distribution inside the patch.
For the end fire array antenna, 5 Multi bands are attained. Return loss obtained is -14.9 dB, -11.3 dB, -18.5 dB, -23.7 dB, -16.12 dB at frequency 1.3 GHz, 2.8 GHz, 3.6 GHz, 4.5 GHz, 5.6 GHz respectively. Gain obtained from the antenna is 5.6 dB. Figure 14 depicts the $S_{11}$ VS Frequency (GHz) plot of end fire array antenna and its modified antennas.

Fig. 14. $S_{11}$ VS Frequency (GHz) plot of end fire array antenna and its modified antennas.

(a) (b)

Fig. 15. Gain plot of end-fire array antenna and its modified antennas at (a) 0° degree phase, (b) 90° phase.

Fig. 16. $S_{11}$ VS Frequency (GHz) plot of proposed single circular Patch antenna, broadside and end fire antenna.

Fig. 17. Gain plot of proposed single, broadside and end-fire array antennas at 0° phase.
Figure 15 (a) and (b) represents the Gain plot of the end-fire array antenna and its modified antennas at 0° phase and 90° phase respectively. Figure 16 represents the S11 vs frequency for all the three structures and the results are tabulated. Similarly Figure 17 and Figure 18 is representing the gain vs frequency at 5 GHz are shown and the results are tabulated.

Table 2. Performance comparisons of antenna parameters with [10] and proposed end fire array antenna with four port 180° hybrid coupler with required impedance matching stub.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing antenna[10]</th>
<th>Proposed end fire antenna array</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>600 MHz</td>
<td>250 MHz</td>
</tr>
<tr>
<td>S11</td>
<td>-19 dB</td>
<td>-24.88 dB</td>
</tr>
<tr>
<td>No of modes</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Frequency range</td>
<td>3.3-3.7 GHz</td>
<td>0.9-5.6 GHz</td>
</tr>
<tr>
<td>Frequency band</td>
<td>S band</td>
<td>L, S, C bands</td>
</tr>
<tr>
<td>Gain</td>
<td>3.3 dB</td>
<td>5 dB</td>
</tr>
</tbody>
</table>

6 Conclusions and Future Scope

Single circular patch antenna, broadside array and end fire array antenna, including modifications in structure, are designed and simulated in HFSS Software at operating frequency of 5GHz. Antenna designs meet the design specifications of gain >5dB, S11 < -10dB and multiband applications. In the range of frequency 1-8GHz namely L, S and C frequency bands. Therefore, a single patch microstrip antenna, Broadside array antenna and End fire array-180 degree hybrid is designed, simulated and analysed. the antenna parameters reflection coefficient, current density patterns, gain, at operating frequency of 5GHz.

There are several areas in which there is scope for improvement. Gain and return loss can be improved by extending the distance between input and output. Choose the best model with the least amount of inaccuracy. Changing the length of the ground and even adding slits to it are two more ways to get the best microstrip multiband antenna. There is potential to try these strategies as well in order to decrease the frequency below 5GHz. The designed
multiband antenna is evidence that it is possible to build high-performance products that benefit the larger objective of sustainability.

References

1. Mr. Navneet Kumar & Dr. Narinder Sharma, IJECE, Volume 6, June 2019.
11. Oğuzhan Kızılbey, Osman Palamutçuoğlu, 3.3 - 3.7 GHz 180 Degree Hybrid Coupler Design, Conference at Istanbul Technical University, 2011.


