Novel Compact Patch Antenna for Ultra-Wideband (UWB) Applications

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Abstract- In this paper, a new ultra-wideband (UWB) antenna is proposed for C-band satellites applications. The main objective of this work is to design an ultra-wideband omnidirectional antenna with a high gain. The proposed antenna is supposed to cover the UWB range from 7.8 GHz to 10.25 GHz for radar applications, and the frequency of 6.3GHz for land stations for satellites. Such a wideband from 7.8 to 10.25GHz is achieved using different slots technologies by etching various shaped slots in the radiating patch. The final antenna has almost invariant radiation properties and reasonable omnidirectional radiation patterns with a gain up to 9.77dB. The antenna is designed on an FR4 substrate with dimensions of (40 × 40 ×1.6mm³). The details of the simulated and measured results for reflection coefficient, gain surface Current distributions and radiation patterns are presented and discussed.

Index Terms- Ultra-wideband (UWB) antenna, Patch antenna.

I. INTRODUCTION

Since the Federal Communication Commission (FCC)’s choice to allow unlicensed operation band from 3.1 to 10.6 GHz in 2002 [1-2], ultra-wideband (UWB) antennas have been widely adopted in communication systems of commercial and military domains. For numerous applications, these antennas must be compact, low cost, and must present good radiation patterns.

The micro-strip slot antenna have many advantages such as light weight, low cost and ease of integration with printed technology [3]. They are used in multiple practical applications and have been widely engaged for the civilian and military applications.

In this paper, we propose an UWB patch antenna with 2 slots, to cover the UWB range from 7.8 GHz to 10.25 and the frequency of 6.3GHz for C-band satellites applications. The antenna design must satisfy the antenna characteristics of wide impedance bandwidth, high gain, omnidirectional radiation pattern, and small compact size. The proposed antenna is successfully designed, fabricated and measured. The measured return loss and the gain spectrum of the antenna are included in results, showing the successful bands for the applications of the antenna. The antenna performs respecting characteristics on the good impedance matching band and radiation patterns over the entire UWB.
II. ANTENNA DESIGN AND CONFIGURATION

The design, parametric study and analysis of the antenna are performed using Computer Simulation Technology (CST) Microwave Studio. The design procedure is aimed at obtaining an antenna enabling operability with higher UWB band and satellites in the C-band. Toward this end, the antenna is required to exhibit a good impedance matching and stable radiation properties in the frequency range from 7.5 GHz up to 10.25 GHz and for the frequency of 6.3 GHz.

A. Theory of Split Ring Resonator

The dielectric constant of substrate material have the most sensitive impact on antennas performance [4]. The change in dielectric substrate material affect the performance of the antenna and its operating frequency [5-6]. Among the various substrates available, FR4 is the suitable substrate for this antenna due to its better utilization of bandwidth, resonating frequency and return loss [7]. The proposed antenna is based on a rectangular-shaped radiating element with two slots: In addition to the single SSR (Split ring resonator) with one cut, a square-rectangular slot is needed in order to get the right bandwidth and to achieve multi-resonance performance in UWB range.

Many split ring resonator parameters affect the performance of the micro-strip patch antenna design. It is possible to obtain magnetic resonance for single ring with a split without using the conventional SRR design where we need two concentric rings with splits at opposite sides [8-9]. The slot width of the inner and outer split ring - used in our structure in figure 2- is varied to study the effect of changes to the antenna parameters such as return loss, gain, directivity, and efficiency [10]. The key aspect is the fact that the wide bands can be obtained. Hence, these structures are especially suited for the design of wideband filters [11].

B. Antenna design

Fig. 2 shows the geometry of the UWB antenna. The proposed antenna is 40 mm × 40 mm in size, and an FR-4 substrate (thickness h = 1.6 mm, permittivity $\varepsilon_r = 4.3$) is used, and placed vertically 0.7 mm above the 40×40 mm ground plane. The antenna is excited by a 50-$\Omega$ micro-strip feed line (line width 3 mm and line length 7 mm). The dimensions of the patch in the form of length and width are calculated using the following formulas:
Width formula of rectangular:

\[ W_p = \left( \frac{c}{2f_r}\right) \left( \frac{\varepsilon_r + 1}{2} \right)^{-0.5} \]

Where \( c = 3 \times 10^8 \text{ ms}^{-1} \) and \( \varepsilon_r = 4.3 \)

Formula of effective dielectric constant:

\[ \varepsilon_{\text{eff}} = \left( \frac{\varepsilon_r + 1}{2} \right) + \left( \frac{\varepsilon_r - 1}{2} \right) \left( 1 + \frac{12h}{W_p} \right)^{-0.5} \]

At \( h=1.6\text{mm} \)

Formula of length extension:

\[ \Delta L = 0.412h \left( \frac{\varepsilon_{\text{eff}} + 0.3}{\varepsilon_{\text{eff}} - 0.258} \right) \left( \frac{W_p}{h} \right) + 0.264 \]

Length formula of rectangular:

\[ L_p = \left( \frac{c}{2f_r\sqrt{\varepsilon_{\text{eff}}}} \right) - 2\Delta L \]

The antenna has three major parts – patch, feed and feed end part [17-18]. Feed line is located at the bottom of the antenna, connected the patch and the source signal. Essentially, the dimensions of the micro-strip feed line were optimized by achieving a parametric analysis of \( b, c, e \) and \( f \) while maintaining the rectangular shape of the patch, and the characteristics of the utilized substrate.

We designed the UWB disc monopole, with the criteria of an impedance bandwidth from 7.5 to 10.25 Ghz and a narrow band of 6.3 Ghz. Fig.3 presents simulated reflection coefficient of the proposed antenna, the antenna without feed-end part and the antenna without SRR slot, We notice that the proposed antenna is the best candidate to meet the requirements in terms of bandwidth.
III. RESULTS AND DISCUSSION

After the design procedure, the antenna was fabricated on FR4-lossy substrate (40×40×1.6 mm). To verify the performance of the proposed approach, the UWB antenna was measured after fabrication. Simulation and measurement results of reflection coefficient, surface current distributions, gain and radiation patterns of the proposed antenna are investigated in this section. Fig. 4 shows the fabricated antenna and Fig. 5 is a picture of the antenna inside Satimo StarLab near-field antenna measurement system during the measurement process.

The simulation and measurement results of S11 parameter are shown in Fig. 6. By imposing the following constraint, the first requirement has been conveniently set in terms of scattering parameters:

$$|S11(f)| \leq -10dB \quad f \in \{f_L, f_H\}$$

The simulated antenna is complying with expected properties. There is a good agreement in resonant frequencies between the simulation and measurement results. The fabricated antenna’s bandwidth starts from 7.8GHz and extends up to 10.25GHz with a narrow band at
6.3 GHz. We notice that we have four resonances frequencies at 6.3, 8, 8.9 and 9.8 GHz.

Figure 6 Measured and simulated reflection coefficient of the UWB antenna

A. Simulated surface Current Distribution

In order to give a physical perception and have a deeper insight on the resonant behavior of the antenna, surface current distribution has been depicted in Figures 7 and analyzed at discrete frequencies of (a) 6.3GHz (b) 8GHz (c) 8.9GHz (d) 9.8GHz.

According to the simulated surface current distributions in Fig 7 (a), (b) and (d) shows that most of surface currents are condensed in the slot. The surface current distributions are mainly flow and distributed though along the SRR, rectangular slots and feed end part. The resonance at 9.8 GHz is due to the modified feed-end part as it shows maximum current. Effective coupling between different slots provides wide-band matched impedance bandwidth and as a result, the surface current is distributed uniformly over the radiating patch.

B. Comparison with other referred works

In order to support the concept of design, a comparative study is reported in Table 2 with some of published UWB antenna in terms of their dimensions, slots, gain and applications. The nearly stable radiation pattern with a maximum gain of 9.77 dB makes the proposed antenna suitable for being used in satellites and radars applications.
Table 2 Comparison with other referred works

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dimensions (in mm)</th>
<th>Bandwidth UWB</th>
<th>Slot</th>
<th>Gain at resonant frequency (dB)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>[19]</td>
<td>13X15</td>
<td>3.07-11.64</td>
<td>Triangular</td>
<td>5.49</td>
<td>UWB applications</td>
</tr>
<tr>
<td>[20]</td>
<td>22x24</td>
<td>2.8-11.4</td>
<td>Tapered Rectangular</td>
<td>3.6</td>
<td>5.4</td>
</tr>
<tr>
<td>[21]</td>
<td>29x32</td>
<td>4-6.5</td>
<td>Rectangular</td>
<td>3.5</td>
<td>5.3</td>
</tr>
<tr>
<td>Our work</td>
<td>40x40</td>
<td>7.8-10.25</td>
<td>Single SRR, Rectangular</td>
<td>4.73</td>
<td>7.73</td>
</tr>
</tbody>
</table>

C. Gain and Radiation Pattern

Figure 8 presents three-dimensional plots of the simulated antenna total gain at four frequencies 6.3, 8, 8.9 and 9.8 GHz in relative coordinate system (X',Y'Z') where X'=X, Y'=Z and Z'=Y. The antenna presents almost invariant radiation properties and reasonable omnidirectional radiation patterns as confirmed by the plots.

Figure 8. 3D radiation patterns at (a) 6.3, (b) 8, (c) 8.9 and (d) 9.8 GHz.

It can be seen from the spectrum of impedance performance in Fig. 6, that there are four resonances around the frequencies at 6.3, 8, 8.9 and 9.8 GHz. They correspond to the different modes of field distribution and play important roles on the explanation of the radiation patterns. The electric field distributions of these resonant modes are then simulated and the correspondent radiation patterns are investigated at 7.9 and 10.25 GHz, as shown in Table 3. The measured results have little deviation from the simulated ones, but two results are matched reasonably with each other. The testing environment and manufacturing tolerance leads to a discrepancy between measured and simulation results.

Table 3 Radiation pattern at the frequency of 7.9 GHz and 10.25 GHz for Phi=0, Phi=90 and Theta=90

<table>
<thead>
<tr>
<th>Frequency Plans</th>
<th>7.9 GHz</th>
<th>10.25 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-plane Phi=0, XZ plan</td>
<td>Simulated - Measured</td>
<td>Simulated - Measured</td>
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</table>
Beam pattern measurements were completed in the frequency domain for the proposed antenna inside Satimo StarLab near-field antenna measurement system. To assess and confirm the outcomes from the simulated results on the radiation properties of the prototype, the realized gain has been measured at the cut planes $\phi =0^\circ$ (XZ plane), $\phi=90^\circ$ (YZ plane) and $\Theta=90^\circ$ (XY plane) (Table 3) at 7.9 GHz and 10.25GHz. It is seen from the figures, that the E-Plane (XZ plane) radiation patterns resemble dumbbell shape while the H-Plane (YZ plane) patterns are quasi-omnidirectional. Due to this acceptable quasi omnidirectional radiation pattern, the proposed antenna can receive information signals from all directions. From Table 3, we can observe that the gain not only depends on the frequency, but can also depend on the direction ($\phi$, $\Theta$). As expected, the measurements satisfactorily match the simulated data with little differences caused by tolerances in the manufacturing process and the measurements.

IV. CONCLUSION

This paper proposes an UWB patch antenna for radars and satellites applications. The antenna is simulated and fabricated on FR4-lossy substrate. The antenna system has compact dimensions of 40x40x1.6 mm. The proposed antenna has been validated and confirmed numerically and experimentally. A good agreement in terms of the return loss and radiation patterns is shown in the results. Accordingly, the proposed antenna is expected to be a good candidate for UWB applications.

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REFERENCES


