A Compact MIMO Antenna For UWB Applications

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Abstract - The communication industry field is mainly focused by high data transfer and more channel capacity in mobile communication. The monopole resonator antenna which is used to radiate in the omni - directional pattern is used for multi broadcasting. Ultra wide band antenna technology is used for transmitting the information through large bandwidth. The proposed work is to design an Ultra Wide Band two-square monopole antenna. The designed antenna has low profile of complexity and it is used to increase the frequency band level. The resulting antenna reduces the overall insertion loss and return loss. The substrate used is FR-4 (Flame Retardant) which has dielectric constant of 4.4. This antenna requires low cost and compact size. This ultra wide band antenna provides ease to the integration of devices. In this paper, the performance of using circular patch with and without slots and the square patch with and without ground stub and slots and strips are analyzed and compared. It is shown that square patch with the ground stub using slots and strips are having the expected performance.

Keywords-ultra wide band (UWB), multiple-input-multiple-output (MIMO), compact antenna

I. Introduction

Antennas are a very important component of communication systems. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern.

Various MIMO antenna for UWB applications were proposed earlier. A multiple input multiple output (MIMO) band notched antenna for portable Ultra Wide Band applications consisting of two square monopole antenna elements, a vertical T-shaped ground stub to reduce the mutual coupling and two strips on the ground plane to create a notched frequency. The antenna can operate at the frequency range of 3.1GHz to 11GHz with notched frequency of 5.15 - 5.85 GHz. A MIMO antenna for portable UWB applications consists of two planar monopole antenna elements with micro strip-fed printed on one side of the substrate and placed perpendicular to each other to achieve good isolation. To achieve better isolation and to increase impedance matching, two long protruding ground stubs are added to the ground plane on the other side. A short ground strip is used to connect the ground planes of the two PMs together to form a common ground.

A novel compact printed ultra wideband slot antenna for MIMO/diversity application consisting of two modified coplanar waveguides feeding staircase shaped radiating elements for orthogonal radiation patterns, where rectangle stub was placed at 45 degree between CPW to ensure high isolation. By etching the two split ring resonator, band notched property was achieved. This antenna was proved to be suitable for MIMO antenna for portable devices. But this antenna of antenna has relatively larger size. A compact dual band-notched ultra wideband MIMO antenna with high isolation was designed with FR4 as a substrate. Two antenna elements are connected to the two protruded ground parts to improve the impedance matching and isolation frequency. A rectangular metal strip was used to produce a notched frequency of range 5.15 - 5.85 GHz. The metal strip was connected to the protruded ground parts to reduce the mutual coupling. The resulting antenna size was relatively small but the reflection coefficient and the total efficiency was not good enough for suppressing interference.

The Ultra wide band MIMO antenna which covers WCDMA (1.92 - 2.17 GHz), Wi-Max (2.3, 2.5 GHz), WLAN (2.4 GHz), UWB (3.1 - 10.6 GHz) bands for wireless device applications consists of printed folded monopole antenna coupled with a parasitic inverted-L element with an open stub inserted in the antenna to reject the WLAN band which interfere with the UWB band. The two antennas are arranged symmetrically on the mobile device substrate. Here, the antenna structure was little complicated and required high fabrication accuracy. Dual-slot element antenna with parasitic monopoles for mobile terminals was used. Double coupling path was introduced which create a reverse coupling to reduce mutual coupling. Parasitic elements are used to reduce the mutual coupling.

A magneto-dielectric (MD) material used has allowable magnetic loss and moderate permeability.
suitable for wireless communication band. A quad bad monopole antenna was used with the MD material. Advantage of MD material over other dielectric material was antenna miniaturization and bandwidth expansion for LTE. A novel dual band 4 shaped printed MIMO antenna with two elements was suitable for LTE wireless handheld devices and portable applications. The achievable low frequency was 803-823 MHz and achievable high frequency was 2440-2900 MHz. The isolation after using defected ground plane structure between the two elements for low frequency band was 17dB and that of high frequency band was 9dB.

A compact planar ultra wide band (UWB) antenna with band notched characteristics has the shape of radiation element and ground plane modified with two symmetrical bevel slots on the lower edge of the radiation element and on the upper edge of the ground plane to make the antenna different from the rectangular printed monopole. These slots improve the input impedance bandwidth and the high frequency radiation characteristics. An additional small radiation patch was introduced to develop a frequency-notched antenna. A compact printed UWB MIMO antenna system was proposed which was operating at a frequency of 3.1 to 10.6 GHz. The wide band isolation was achieved through a tree-like structure on the ground plane. It is suitable for portable UWB applications.

In this paper, we propose a novel antenna design for UWB radio systems. Omni-directional radiation patterns and stable gain are obtained. An in-house developed computational tool based on the Finite Element method (FEM) and the MATLAB programming environments are used for simulation works. This printed patch antenna is low profile antenna, contented to planar and non-planar surfaces, simple and inexpensive to manufacture from present day printed technology. It is also usually inexpensive to manufacture and design. For improved antenna function, a wide dielectric substrate having a low dielectric constant is advantageous this provides better capability, superior bandwidth and better radiation. Still, such a proposed design leads to a bigger antenna size. In designing a compact patch antenna, the materials having higher value of dielectric constant must be used which are less dexterous and results in narrow bandwidth. Hence conciliation must be reached between antenna dimensions and antenna performance. Hence the substrate used in this antenna design is FR-4 with dielectric constant 4.4 which relatively higher value.

II. Design of the proposed antenna

The geometry of the proposed antenna is shown in the figure 1. A T-shaped ground stub is used because the size of the antenna can remain compact and it also serves as a reflector. The two main functions of using T-Shaped Ground Stub are: i) providing better matching for the antenna and ii) enhancing the isolation by reflecting the radiation from the radiators. Without the use of the T-shaped ground stub, the antenna has lower cut-off frequency and the mutual coupling as almost > -15dB. The ground slot cut on the T-shaped stub helps in enhancing the isolation.

The fundamental resonant frequency of a planar monopole antenna is given by,

\[
f_r = \frac{144}{l_1 + l_2 + g + \frac{A_1}{2\pi l_1 \sqrt{\varepsilon_{re}}} + \frac{A_2}{2\pi l_2 \sqrt{\varepsilon_{re}}}}
\]

Where,

\(l_1\) - length of the ground plane, \(l_2\) - length of the radiation patch, \(g\) - gap between the ground plane and patch, \(A_1\) - area of the ground plane, \(A_2\) - area of the radiation patch, \(\varepsilon_{re}\) - effective dielectric constant

Figure 1: Prototype of the Proposed Antenna

Simulation on S parameters of the MIMO antenna with and without the use of T-shaped stub, are shown in Figure 2(a), 2(b).
Due to the symmetrical structure of the antenna, S22 and S12 are same as S11 and S21, respectively.

The simulated impedance bandwidths (for S11< −10 dB) of the antenna with and without the ground slot do not vary much and are from 2.8 GHz to more than 11 GHz. But without using the ground slot, the mutual coupling between the two input ports of the antenna is larger than −15 dB (i.e., S21>−15 dB) in the frequency below 5 GHz, which is not low enough for good performance. With the use of the ground slot, a resonance at about 2.6 GHz is generated, lowering S21 down to below -15 dB. Current distribution helps to study the effects of the ground slot on isolation. When a ground slot is cut on the T-shaped ground stub, mutual coupling between the two ports are highly reduced.

The measured correlation coefficient is very low and hence the correlation between the two ports is low which yields a good diversity performance. A convenient metric to optimize capacity is multiplexing efficiency which determines the multiplexing performance. The proposed system thus has an advantage of designing antenna with low cost, high gain and reduced return loss and insertion loss. The resulting antenna can be easily integrated with the other devices.

A. Patch Design Measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UNIT (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W$</td>
<td>36</td>
</tr>
<tr>
<td>$W_{G1}$</td>
<td>2</td>
</tr>
<tr>
<td>$W_{G2}$</td>
<td>20</td>
</tr>
<tr>
<td>$W_{f1}$</td>
<td>3.5</td>
</tr>
<tr>
<td>$W_{f2}$</td>
<td>0.5</td>
</tr>
<tr>
<td>$W_i$</td>
<td>1</td>
</tr>
<tr>
<td>$W_d$</td>
<td>0.5</td>
</tr>
<tr>
<td>$d_f$</td>
<td>5</td>
</tr>
<tr>
<td>$L$</td>
<td>22</td>
</tr>
<tr>
<td>$L_{G1}, L_{G2}$</td>
<td>8.4</td>
</tr>
<tr>
<td>$L_{f1}, L_{f2}$</td>
<td>3.6</td>
</tr>
<tr>
<td>$L_s$</td>
<td>17</td>
</tr>
<tr>
<td>$L_t$</td>
<td>8.3</td>
</tr>
<tr>
<td>$L_r$</td>
<td>8</td>
</tr>
</tbody>
</table>

B. Patch Design Calculations

Step 1: Calculation of the Width (W)


\[ W = \frac{c}{2f_0 \sqrt{(\varepsilon_r + 1)/2}} \]  

(2)

**Step 2:** Calculation of the Effective Dielectric Constant. This is based on the height, dielectric constant of the dielectric and the calculated width of the patch antenna.

\[ \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} [1 + 12 \frac{h}{W} \frac{1}{\varepsilon_r}] \]  

(3)

**Step 3:** Calculation of the Effective length

\[ L_{eff} = \frac{c}{2f_0 \sqrt{\varepsilon_{eff}}} \]  

(4)

**Step 4:** Calculation of the length extension \( \Delta L \)

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

(5)

**Step 5:** Calculation of actual length of the patch

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

(6)

**C. Results and Discussions**

The antenna design was analyzed using:

i) Circular Patch – with and without T-shaped ground stub and with and without the slot at the center of the patch.

ii) Square patch - with and without T-shaped ground stub and by varying the size of the radiating patch.

**D. Parameter evaluation**

i) S – Parameters

The \( S \) – parameter is measured using Vector Network Analyzer (VNA) Rohde & Schwarz ZVA 24. The simulation result for the antenna design using circular and square patch with and without slot are compared. The corresponding figures are given below in the figure 3.
ii) VSWR

The Voltage Standard Wave Ratio (VSWR) corresponding to the S parameter is measured. The range of VSWR lies between 1 and 2. This shows the proper working of the antenna. Figure 4 represents the corresponding VSWR for the different antenna design.

iii) Radiation Pattern

The corresponding radiation pattern for the proposed antenna design was plotted. It is also represented in this 3D polar plot. The radiation pattern with its 3D-Polar plot is shown in the figure 5.
Figure 5(a) Circular Patch
Figure 5(b) Circular Patch with Slots
Figure 5(c) Circular Patch with only the lower Stub
Figure 5(d) Circular Patch with slot with T-shaped ground stub
Figure 5(e) Square Patch with only the Lower Stub
Figure 5(f) Square Patch (6mm)
Figure 5(g) Square Patch (10mm)
Figure 5(h) Square Patch (Roger Substrate)
Figure 5(i) Square Patch (FR - 4)
### Table 1.3 Comparison Table for all the antenna Design mentioned.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Designs</th>
<th>Bandwidth</th>
<th>Return loss (dB)</th>
<th>VSWR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Circular Patch without Slot with T-shaped ground stub</td>
<td>13.5 GHz (0-16.5 GHz)</td>
<td>-17.5</td>
<td>1.3</td>
</tr>
<tr>
<td>2.</td>
<td>Circular Patch with Slot with T-shaped ground stub</td>
<td>7.5 GHz (2-10 GHz)</td>
<td>-11.5</td>
<td>1.75</td>
</tr>
<tr>
<td>3.</td>
<td>Circular Patch without slot with lower Ground Stub</td>
<td>7.25 GHz (2-10GHz)</td>
<td>-12.5</td>
<td>1.65</td>
</tr>
<tr>
<td>4.</td>
<td>Circular Patch with slot with lower Ground Stub</td>
<td>7.25 GHz (2-10GHz)</td>
<td>-12.8</td>
<td>1.58</td>
</tr>
<tr>
<td>5.</td>
<td>Square Patch with lower ground stub</td>
<td>7.5 GHz (2-10GHz)</td>
<td>-17.25</td>
<td>1.32</td>
</tr>
<tr>
<td>6.</td>
<td>Square Patch with T-shaped stub (6mm)</td>
<td>7.25 GHz (2-10GHz)</td>
<td>-14.25</td>
<td>1.48</td>
</tr>
<tr>
<td>7.</td>
<td>Square Patch with T-shaped stub(10mm)</td>
<td>5 GHz (2-10GHz)</td>
<td>-14.75</td>
<td>1.5</td>
</tr>
<tr>
<td>8.</td>
<td>Square Patch with T-shaped</td>
<td>5.8 GHz (2-10GHz)</td>
<td>-12.6</td>
<td>1.48</td>
</tr>
</tbody>
</table>

**III. Conclusion**

Finally, Ultra wide band two-square monopole antenna was designed to improve the gain level compared to existing technology. This design is to cover the ultra wide band frequency level based on MIMO applications. An MIMO antenna with a compact size of 22× 36 mm² has been designed for portable UWB applications. Two square monopole antenna elements are used to provide UWB operation from 3.1 to 10.6 GHz. A T-shaped ground stub with a slot is used between the monopole elements to reduce mutual coupling. The envelope correlation coefficient is below 0.06 throughout the UWB. The antenna design with the circular and square patch with and without the slots are compared for its performance and it has been shown that square patch with T-shaped ground stub with slots using FR-4 substrate was proved to be the best design. Results indicate that the MIMO antenna is suitable for portable UWB MIMO applications.

**Acknowledgment**

**References**


Author
S D Priya Sankari PG Scholar,
KLN College of Information Technology,
Pottapalayam, Sivagangai District. I am pursuing my PG graduation and on behalf of my project, I am presenting this paper.