A Two Step Stair Shaped Dielectric Resonator Antenna with AMC for UWB Applications

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Abstract

This paper presents an ultra-wide band (UWB) antenna with two steps stair shaped dielectric resonator (SSDR) antenna. The two steps SSDR is placed precisely on the aperture to achieve an ultra-wide bandwidth of 136.2%. The first step of SSDR (DR1 and DR2) is fed directly by the microstrip line through aperture coupling technique whereas the second step (DR3) is a parasitic DR placed adjacent to DR1. The SSDR is radiating with TE_y1δ1–like mode at 5.32 GHz and TE_xδ11–like mode at 6.3 GHz. The parasitic DR is improving the impedance matching and increasing the bandwidth by 11.3% due to the dielectric loading effect. Further a dual band artificial magnetic conductor (AMC) is placed below the UWB antenna to improve the antenna radiation characteristics. The improvement in average gain and gain variation is 36.7 % and 13.5% respectively. The antenna radiation efficiency is 81.6% with AMC reflectors.

1. Introduction

Dielectric resonators are the most attractive choices for evolving wireless communication systems in the coming years. It has advantages when it comes to ohmic losses, bandwidth enhancement, and integration with different feeding networks and radiating elements. Since Long et al. [1] identified dielectric resonators as radiators in 1983, their application to various communication scenarios has been a research focus for decades. These resonators have been investigated as a single band, multiband, and wideband radiators for different applications. [2]. A unique type of antenna called as an ultra-wideband antenna is modernizing the communication system. [3]. Its ability to integrate into many type of indoor communication systems for smart devices makes it particularly effective in intelligent communication systems. These antennas are not only competent, but they are also safe, dependable, and cost-effective, with a high data rate. Unlike other wireless communication systems, identification of other UWB devices is not dependent on signal strength but based on the time it takes for a short radio pulse to travel between devices utilizing techniques such as Time of Flight (ToF), Time Difference of Arrival (TDoA), etc. [4-5]. As a result, it is considerably more precise and different than other wireless technologies. Most of the DR-based UWB
antennas reported [6-9], so far are hybrid antennas, i.e., the integration of dielectric resonators with the planar structures. The technique involves the modification in DR-shape, introduction of air-gaps, and stacking of DRs in order to reduce the overall quality factor of the antenna, hence improving the bandwidth.

In this paper, a modified two step stair shaped DR (SSDR) is presented, which is radiating along with the aperture created on the ground plane to achieve ultra-wide bandwidth. The proposed UWB antenna is investigated in terms of reflection coefficient, gain, radiation pattern, and radiation efficiency. Further, an AMC structure is placed beneath the proposed antenna and antenna far field parameters are studied.

2. Antenna Design and Analysis

2.1 Antenna Design

The antenna design evolution is shown in Figure 1. The corresponding reflection coefficient at each step in design evolution is shown in Figure 2.

![Figure 1](image1)

![Figure 2](image2)

**Table 1**

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Frequency Bands (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Nil</td>
</tr>
<tr>
<td>B</td>
<td>3.38 to 4.46, 8.00 to 12.3</td>
</tr>
<tr>
<td>C</td>
<td>3.46 to 4.68, 6.47 to 7.8, 8.42 to 10.87</td>
</tr>
<tr>
<td>D</td>
<td>3.35 to 5.82, 6.25 to 10.83</td>
</tr>
<tr>
<td>E</td>
<td>3.32 to 11.8</td>
</tr>
</tbody>
</table>

The antenna is designed on a FR-4 epoxy substrate of thickness 0.8 mm, \( \varepsilon_r = 4.4 \) with loss tangent of \( \tan\delta = 0.025 \). Referring to Figure 1 and Figure 2, Antenna ‘A’ is simply a partial ground plane fed by a microstrip line on the back side of substrate. Antenna ‘A’ does not resonate but after creating a rectangular slot in the partial ground plane (Antenna ‘B’) a possibility of resonance is observed. Further, another slot is created in addition with the existing slots, thus modifying the overall slot (Antenna ‘C’) and two resonance bands are observed in the lower and higher frequency region. A second slot is created in the defected ground plane (Antenna ‘D’) which improves the impedance matching in the higher frequency region. A third slot which is a rectangular slot, is created as shown in Antenna ‘E’ which shows similar behavior to Antenna ‘C’ and ‘D’. Two resonance bands i.e., 3.38 GHz to 4.46 GHz and 8 GHz to 12.3 GHz are obtained. From Antenna ‘C’ to Antenna ‘E’, impedance matching is improved hence bandwidth is improved, but the resonance frequency range are similar. On placing the first DR i.e., DR1 as shown in

**Figure 3** (a) TE \( \gamma_{10} \) – like mode at 5.32 GHz, (b) TE \( \gamma_{31} \) – like mode at 6.3 GHz on the two step stair shape DR.

![Figure 3](image3)

![Figure 4](image4)

![Figure 5](image5)

**Figure 4**. (a) Perspective view showing the dimensions of the DR (\( \varepsilon_r \) (Alumina) = 9.8), \( d_1 = 10, d_2 = 9.5, d_3 = 12, d_4 = 7, d_5 = 6.5 \) and \( d_6 = 8 \) (b) Back view of the antenna showing feed line dimensions, \( f_1 = 1.5 \) and \( f_2 = 22 \) (All dimensions are in mm)

**Figure 5**. Radiation pattern of the proposed UWB antenna. They are similar. On placing the first DR i.e., DR1 as shown in Antenna ‘F’, a multi-band response is obtained due to the DR1 resonance and aperture resonance. Adding DR2 adjacent to the DR1 which together creates the first step in stair shape DR (Antenna ‘G’). Due to the dielectric loading, overall increase in the size of the DR and change in shape from its regular geometry, the resonance of the first step...
DR shifts to lower frequencies i.e., 5.32 GHz and 6.3 GHz. It can be observed that the aperture resonance at higher frequency is shifted to lower frequency due to the dielectric loading of the DRs on the aperture. Finally, a third DR i.e., DR3 is loaded on the third slot (Antenna ‘H’). This DR is acting as a parasitic DR to the first step stair DR. This DR improves the impedance matching and bandwidth at higher frequencies, thus achieving the bandwidth from 3.32 GHz to 11.8 GHz. The DR modes at the resonance frequencies 5.32 GHz and 6.3 GHz are TEγ10− like and TEγx11− like as shown in Figure 3. It can be observed from the electric field distribution on the two step SSDR of Figure 3, that the parasitic dielectric resonator DR1 is not actively participating in DR modes rather DR1 and DR2 are contributing towards modes of two step SSDR. Table – I show a tabular representation of the frequency bands corresponding to antenna evolution at each design step in Figure 1. Figure 4. shows the perspective view and of the proposed structure and the antenna feed line.

2.2 Antenna Design with AMC

The proposed antenna designed so far shows a degradation in the antenna radiation characteristics. So to improve the antenna radiation performance, an AMC structure has been designed. Figure 6 (a). shows the unit cell design of the AMC structure. A dual band AMC structure is chosen for covering the maximum band of operation throughout the ultra-wide bandwidth.

Figure 6. (a) Proposed AMC unit cell design, C1 = 8, C2 = 5, C3 = 1.2, g1 = 0.3, g2 = 0.2, g3 = 0.2, t = 2.4 and s = 0.5 (All dimensions are in mm). (b) Proposed UWB Antenna with AMC structure, W1 = 40 mm.

Figure 7. Phase reflection coefficient of proposed AMC structure.

The impact of AMC structure on the radiation efficiency curve is shown in Figure 10. It is observed that the radiation efficiency on average for UWB antenna is 84.45 % where as when AMC structure is included, it is 81.58 %. Also, the blue and red curve (showing efficiency) are well following each other. This shows, that the efficiency is not degrading significantly and the AMC structure is not showing any strong coupling effects with UWB antenna structure. Hence, a significant improvement in antenna radiation characteristics is achieved. Referring to Figure 5. and Figure 11., the effect on radiation pattern due to AMC structure can be compared. The UWB antenna has inconsistency in its radiation pattern. The pattern is omni-directional, directional and tilted in backwards due to antenna geometry. Whereas, with the implementation of AMC structure in the antenna geometry, the radiation
pattern is improved significantly and the patterns are consistent throughout the operating range. A directional pattern is observed throughout the achieved ultra wide bandwidth which is suitable in most of the communication applications.

### Table II

<table>
<thead>
<tr>
<th>Performance Parameters</th>
<th>UWB Antenna</th>
<th>UWB Antenna with AMC</th>
<th>% Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Gain (dBi)</td>
<td>3.31</td>
<td>5.23</td>
<td>36.7</td>
</tr>
<tr>
<td>Gain stability (dBi)</td>
<td>3.18 (2.5.18)</td>
<td>&lt;2.75 (3.92-6.7)</td>
<td>13.5</td>
</tr>
<tr>
<td>Radiation Pattern</td>
<td>back-lobes and backward radiation</td>
<td>Directional radiation pattern and reduced backlobes</td>
<td>-</td>
</tr>
</tbody>
</table>

3. Conclusion

In this paper, a two step stair shaped dielectric resonator (SSDR) antenna is presented which gives ultra wideband characteristics. The DR₁ and DR₂ are contributing along with aperture towards ultra wide bandwidth and radiation characteristics. The DR₃ which is adding the second step in SSDR antenna is a parasitic DR that improves the impedance matching and the antenna bandwidth due to the dielectric loading effect. A dual band AMC structure is placed below the UWB antenna that improves the antenna radiation properties significantly. The impedance bandwidth achieved is 136.2%. Antenna gain is improved by 36.7% and stability in gain is improved by 13.5% with less 2.75 dB difference. The proposed antenna has a good radiation efficiency of more than 81%.  

4. References