GAIN ENHANCEMENT IN ULTRA-WIDEBAND ANTENNAS BACKED BY A SUSPENDED GROUND OR COVERED WITH METAMATERIAL SUPERSTRATES

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ABSTRACT

This paper presents compact directional ultra-wideband (UWB) antenna designs with two different techniques. The first design is based on a monopole printed on a RT5880 printed circuit board (PCB) backed by a suspended ground in order to achieve directionality. The other design utilizes a metamaterial superstrate above the monopole antenna. In both cases, directional radiation patterns are achieved. Using a suspended ground achieves more gain enhancement. However, the antenna overall size is smaller using superstrate covering the monopole antenna.

Index Terms— Antenna, directional antenna, ultra-wideband, UWB, miniaturized antenna

1. INTRODUCTION

Since the FCC announced its decision to allow the unlicensed use of the bandwidth of 3.1–10.6 GHz for commercial applications, ultra-wideband (UWB) radio technology has attracted much attention for wireless communication, localization, imaging, radar, and so on [1], [2]. Antennas are considered key components in UWB communication systems. The antenna performance and characteristics influence the design of the whole UWB system. For good UWB antenna design, it should have compact size, good efficiency, and easy integration with circuitry. This is in addition to having minimum time domain distortion for short pulse transmission/reception. Most of the proposed antenna designs for UWB applications exhibit omni-directional radiation patterns similar to the traditional monopole/dipole antennas [3]-[6]. In case of attaching these antennas to walls, metal objects or human body, the antenna performances will be degraded. If a directional UWB antenna is utilized, the degradation on the antenna performance can be avoided. Also, in case of high gain applications, a directional UWB antenna is needed instead of using antenna array. Therefore, it is desirable to develop a UWB antenna with high directional radiation characteristics.

In this paper, compact directional UWB antennas are investigated with two different techniques. One is achieved by using a suspended ground underneath the UWB monopole antenna [3]. Another technique is done by adding a metamaterial superstrate above the monopole antenna. In both cases, directional radiation patterns are achieved.

2. UWB ANTENNA

The geometry of the UWB antenna is presented in Figure 1 with all optimized dimensions summarized in Table 1. The antenna consists of a microstrip-line-fed printed disc monopole with two steps and a circular slot with a finite truncated ground plane, and both are printed on a Rogers RT/duroid5880 high-frequency laminate with thickness of $h$, loss tangent of 0.0009, and relative permittivity of 2.2. The antenna prototype with an overall size of 40 mm × 30 mm × 0.787 mm, achieving impedance matching bandwidth of 9.5 GHz (2.9-11.4 GHz) for reflection coefficient < -10 dB. The simulated gain varies from 1.5 to 4.5 dBi over the UWB band of 3.1-10.6 GHz.
Simulated reflection coefficient $|S11|$ results for the UWB antenna element with a microstrip line feed in Figure 2 show that the antenna element has an UWB frequency response.

![Figure 2 Simulated reflection coefficient $|S11|$ for the UWB antenna element with a microstrip line feed.](image)

Table 1: Dimensions of the antenna element in Figure 1.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W$</td>
<td>30 mm</td>
</tr>
<tr>
<td>$L$</td>
<td>40 mm</td>
</tr>
<tr>
<td>$R$</td>
<td>9.5 mm</td>
</tr>
<tr>
<td>$R_S$</td>
<td>3.0 mm</td>
</tr>
<tr>
<td>$\Delta y$</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>$L_G$</td>
<td>15 mm</td>
</tr>
<tr>
<td>$W_F$</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>$W_N$</td>
<td>3.0 mm</td>
</tr>
<tr>
<td>$h$</td>
<td>0.787 mm</td>
</tr>
<tr>
<td>$L_1$</td>
<td>3.0 mm</td>
</tr>
</tbody>
</table>

### 3. UWB ANTENNA BACKED BY A SUSPENDED GROUND

The configuration of the proposed microstrip-line-fed monopole antenna backed with a suspended ground is illustrated in Figure 3. The proposed antenna comprises a monopole radiator, a feeding structure, and a suspended metallic ground. From the Cartesian coordinate system, the antenna lies in the x-y plane. The suspended metallic ground is positioned underneath the monopole antenna. It has length $L_S$, width $W_S$ and it is located at a distance $d$ from the monopole antenna. By controlling the suspended ground dimensions, it can work as a reflector to increase the gain of the monopole antenna and produce a unidirectional broadside radiation patterns without affecting too much the desirable impedance matching bandwidth over an ultra-wideband frequency range.

Extensive parametric studies have been carried out to investigate the effect of suspended ground parameters on the proposed antenna performance. It can be noticed that in order to further improve the impedance matching of the antenna and reduce the back radiation, the optimized suspended ground parameters should be $L_S = 60$ mm, $W_S = 45$ mm and $d = 20$ mm.

![Figure 3 Geometry of UWB antenna backed by a suspended metallic ground.](image)

The simulated return loss $|S11|$ results for the proposed antenna with a suspended ground compared to the reference antenna (without suspended ground) are shown in Figure 4. The overall impedance bandwidth is almost unchanged with adding a suspended ground. However, resonance frequencies have moved towards the lower frequencies. This is because the proposed antenna looks bigger in size.

![Figure 4 Simulated $|S11|$ for the UWB antenna backed by a suspended metallic ground compared to reference antenna.](image)

![Figure 5 Simulated realized gain for the antenna backed by a suspended ground compared to reference antenna.](image)
Figure 6 Simulated radiation patterns for the UWB antenna backed by a suspended metallic ground.

The maximum realized gain of the proposed antenna compared to the reference antenna is plotted in Figure 5. There is a gain enhancement of at least 3dBi compared to that of reference antenna. Figure 6 presents the simulated radiation patterns for the proposed antenna with a suspended ground at different frequencies $f = 3, 5, 7$ and $9$ GHz. It can be noted that by adding a suspended ground, directive radiation patterns have been achieved.

### 4. UWB ANTENNA COVERED WITH METAMATERIAL SUPERSTRATES

The second proposed technique to increase the directivity of a UWB monopole antenna is discussed here in detail. Figure 7(a) shows the geometry of the proposed antenna, which is composed of a UWB monopole antenna and a superstrate, which have a relative permittivity of $\varepsilon_r = 1$, relative permeability $\mu_r = 50$ and thickness $B = 1.575$ mm. In addition, the metallic printed strips are placed in the lower side of the superstrate as shown in Figure 7 (b). The distance from the ground to the superstrate is calculated to be around $d = 11$ mm. Furthermore, the width of the strips has been set to $WS = 2$ mm to give the most important reflectivity by increasing the fill rate all over the superstrate. The distance between metallic strips is $DS = 1.5$ mm.

Dimensions of the microstrip line are calculated using LINCALC software of Agilent [7] and optimized by Ansoft HFSS [8] and CST microwave studio [9]. The microstrip feed line is designed in order to achieve $50\Omega$ input impedance for matching the characteristic impedance of the measurement system feed line. A parametric study is carried out to investigate the characteristics of the proposed antenna seeking for optimal performance.

The simulated return loss coefficient $|S_{11}|$ curve for the proposed antenna is shown in Figure 8. The curve for the reference antenna (without superstrate) is shown here for comparison. According to Figure 8, it can be noted that the impedance bandwidth for the proposed antenna does not affected by installing metamaterial superstrate layer on the reference antenna.

The simulated realized gain for the UWB antenna covered with metamaterial superstrate is presented in Figure 9. It can be seen that a considerable gain enhancement is achieved, when the superstrate is added. In addition the proposed antenna which we add metallic strips got a maximum gain of $7.5$ dBi observed at $9$ GHz compared to $4.5$ dBi for the reference antenna.
The simulated radiation patterns for the proposed antenna with metamaterial superstrate at different frequencies $f = 3, 5, 7$ and $9$ GHz are introduced in Figure 10. It can be noted that by adding a metamaterial superstrate above the reference antenna, directive radiation patterns have been achieved.

The first design is with an overall size of 45 mm $\times$ 60 mm $\times$ 20.787 mm, achieving the impedance matching bandwidth of more than 11 GHz (2.7 GHz to beyond 14 GHz) for reflection coefficient $< -10$ dB. The calculated gain is about 3 dBi more than that of UWB printed monopole antenna without suspended ground. Using a metamaterial superstrate layer above the UWB monopole antenna, the new structure has an overall size of 41 mm $\times$ 50 mm $\times$ 11.787 mm. The achieved impedance matching bandwidth is about 9 GHz (3.2 GHz – 12.4 GHz) for reflection coefficient $< -10$ dB. The calculated gain is about 3 dBi more than that of UWB printed monopole antenna without superstrate layer especially in the upper UWB frequency band, i.e. 7.0 GHz - 11 GHz.

From Figure 5 and Figure 9, we can see by adding a suspended ground can provide higher gain than covering with superstrate. Moreover, intuitively, the cost of the suspended ground is lower than the superstrate. However, advantages of covering with superstrate compared with adding suspended ground is to achieve a compact structure size.

5. CONCLUSION

The directivity enhancement resulting from placing a suspended ground underneath the UWB monopole antenna or a metamaterial superstrate over it is quantitatively shown by simulation. The radiation patterns results are computed with the full-wave simulator CST. The achieved radiation patterns have directive characteristics. The gain has been enhanced without affecting the antenna matching impedance bandwidth. The superstrate-based gain enhancement method can be used in commercial antennas to combat some of the downsides of the existing systems such as gain decrease due to surface waves and dielectric losses.

6. REFERENCES