Ultra-wideband Antenna with Slotted Ground Structure for Wireless Application

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Abstract. This paper presents a software-based design of an ultra-wideband slot antenna that is applicable for wireless applications. Due to introduction of polygonal wide slot in the ground plane, the ultra-wideband has been achieved. The battery slot and rectangular shapes are implemented to improve $S_{11}$, operating bandwidth range and radiation pattern of antenna. The optimal dimensions of the presented antenna are $45mm \times 45mm \times 1.565mm$ and is simulated on FR-4 substrate with relative permittivity of 4.3 and loss tangent of 0.025. The proposed antenna shows wide impedance bandwidth of 4.56GHz (104%) ranging from 2.08GHz to 6.64GHz that covers WLAN and WIMAX application.

1. Introduction

As the wireless communication systems advance rapidly, the antenna for these system is required to support various radio frequency bands such Worldwide Interoperability for Microwave Access (WiMAX) and 2G/ 5G Wireless Local Area Network (WLAN). From literature survey, the wideband and multiband antennas are knowledgeable to achieve more required bands, wide impedance bandwidth and stable gain [1]–[4]. Microstrip antennas in nature are low profile design and planar structure so they can provide a reliable communication [5]–[7]. Many studies have been carried out by researchers worldwide over the past few decades to achieve different design goals.

To attain ultra-wideband (UWB), several printed antenna have been designed with different features by employing monopole antenna [8], slot antenna [9], ring antenna [10], fractal antenna [11] and shaped antenna [12]. With these techniques, bandwidth enhancement of more than 70% for voltage standing wave ratio (VSWR) ≤ 2 has been reported. However, some of these antennas offer low gain. Printed monopole antenna is an alternative solution to improve size of antenna, gain and bandwidth [13]. Large bandwidth of higher order resonances has been obtained by adding square parasitic patches and U-shaped slit in partial ground plane [14]. Wineglass monopole antenna with slotted partial ground is proposed for bandwidth enhancement in [15]. Bandwidth enhancement of 92.8% has been reported due to implementation of the crescent shape patch with truncated ground plane [16]. In [17] and [18], a shaped patch with slotted partial ground is demonstrated. Octagonal shaped with partial ground has achieved impedance bandwidth of 109% [19]. Triangular shaped slot monopole antenna with partial
ground has attained 142% of operating bandwidth [20]. Small size of antenna with ultra-wideband characteristics is proposed by inserting a droplet and shape stub in the radiating patch with chamfered ground [21]. A rounded corner in patch and partial ground plane has been used to achieve 122% of impedance bandwidth [5]. An antipodal Y-strip slot antenna has increased the impedance bandwidth to 84% [22]. By combining back to back triangular shaped patch, truncated ground and double split ring resonators, bandwidth enhancement of 185% has been attained [23].

In this letter, a wideband-printed structure of the slot antenna developed from the antenna described in [22] is proposed. The antenna is composed of rectangular shaped patch which are excited through a microstrip feedline. Etched in antenna ground plane is a wide polygon and a small rectangular slot located under the radiating patch. These elements have enhanced the impedance bandwidth and improved the return loss and radiation pattern of antenna. The proposed antenna radiates nearly bidirectional radiation pattern with frequency range of 2.08 GHz to 6.64 GHz. The antenna is compact with overall dimensions of 45mm x 45mm x 1.565mm. Table 1 shows the comparison of the proposed antenna with other reported previous wideband antennas in terms of size, frequency range, bandwidth and antenna gain. The proposed antenna has attained a wide fractional bandwidth (FBW) of 104% and covered the overall wireless application with comparable size with the other antennas with gain more than 3dB.

| References | Size (mm$^2$) | Frequency range (GHz) | BW (%) | Gain |
|------------|--------------|------------------------|--------|------|
| [5]        | 55 x 45      | 2.11 – 8.72            | 122    | 2.42 dBi |
| [14]       | 35 x 25      | 2.9 – 16.3             | 139    | 2 – 5.2 dB |
| [15]       | 150 x 100    | 0.7 – 1.3              | 60     | - |
| [16]       | 57 x 37.5    | 1.76 – 4.78            | 92.8   | 2.18 – 2.71 dB |
| [17]       | 30 x 22      | 2.98 – 12              | 120    | 3.95 dB |
| [18]       | 40.6 x 35.26 | 2.6 – 7.1              | 92.8   | 4.31 dB |
| [19]       | 30 x 30      | 3.1 – 10.6             | 109    | 2.21 – 3.98 dB |
| [20]       | 40 x 30      | 2.58 – 15.5            | 142    | 4.96 dB |
| [21]       | 15 x 15      | 3.26 – 20              | 144    | 5.69 dB |
| [22]       | 28 x 28      | 3.25 – 8               | 84     | >3dB |
| [23]       | 48.32 x 43.72| 0.115 – 2.9            | 185    | 2.35 dB |
| This work  | 45 x 45      | 2.08 – 6.64            | 104    | 3.2 – 5.5 dB |

**Table 1.** Comparison of various UWB antenna.

2. Antenna Design Structure

The structure of the proposed slot antenna is presented in Figure 1. The proposed antenna has overall size of 45mm x 45mm x 1.565mm using FR4 substrate with dielectric constant of 4.4 and tangent loss of 0.025. Table 2 shows the geometrical values of the proposed antenna for the different parameters. It comprised of rectangular patch associated with shaped slot on the ground plane.

The top of this antenna consists of the rectangular radiating patch and microstrip feedline. The bottom layer consists of defected ground plane with polygonal wide slot and small rectangular slot. On the ground plane under the microstrip feedline, a gap is introduced to minimize the coupling effect between two copper layers (feedline and ground plane).

Computer simulation of the proposed antenna is carried out using Computer Simulation Technology (CST), a numerical analysis using finite different time domain. The polygonal and rectangular slot on ground plane is introduced to enhance the operating bandwidth. Initially a polygonal wide slot is etched out in the ground plane to widen the bandwidth. Later, the small rectangular slot on ground is introduced overlap to the patch for further bandwidth enhancement. FBW of 104% is obtained covering wireless applications.
3. Result and Discussion
The simulation and optimization of antenna have been carried out to obtain various performance parameters like reflection coefficient, gain and efficiency. Figure 2 shows the simulated return loss, $S_{11} < -10$ dB of the proposed antenna. To significantly improve the impedance bandwidth, the polygonal wide slot is introduced at the ground plane, thus provides the FBW of 104% ranging from 2.08 to 6.64 GHz. At the same bandwidth, the value of simulated VSWR is less than 2, as shown in Figure 3.

![Figure 2. Reflection coefficient of the proposed antenna.](image-url)
Figure 3. Simulated VSWR.

The simulated gain and radiation efficiency response of the proposed antenna is depicted in Figure 4. The peak gain of the proposed antenna is 5.4 dB, whereas gain have been maintained from 3.1 to 5.4 dB over ranging frequencies from 2.08 GHz to 6.64 GHz. It also can be noticed that the peak efficiency response of the proposed antenna is 96%, whereas radiation efficiency has been maintained from 67% to 96% in desired frequency range. As observed from Figure 4, the gain of the proposed antenna for 2 GHz band is lower than 5.2/5.8 GHz band, while the radiation efficiency for 2 GHz band is higher than 5.2/5.8 GHz band.

Figure 4. Simulated gain and efficiency response in operating bandwidth.

The simulated current distributions at the resonant frequencies are shown in Figure 5. At 2.4 GHz, Figure 5(a), shows that the surface currents are more concentrated along the microstrip feedline which is similar to that of Figure 5(c) at 5.2 GHz. Figure 5(b) shows that the current are mainly distributed at the lower part of the feedline, thus determine the frequency, 3.5 GHz, whereas at 5.8 GHz, the current also flow along the upper part of the wide slot as shown in Figure 5(d). Radiation patterns in both E-plane (yz-plane) and H-plane (xz-plane) at various frequencies are plotted in Figure 6. To further improve the antenna performance, the battery slot with rectangular shapes are added at the ground plane resulted nearly stable radiation pattern for the entire band of operation. The proposed antenna has an omnidirectional radiation pattern in H-plane and nearly bidirectional radiation pattern in E-plane over most of the desired operating frequency band.
Figure 5. Simulated surface current distribution at (a) 2.4GHz (b) 3.5GHz (c) 5.2GHz (d) 5.8GHz.

Figure 6. Radiation patterns at (a) 2.4GHz (b) 3.5GHz (c) 5.2GHz (d) 5.8GHz.
4. Conclusion
A printed wideband antenna with slotted ground is proposed for wireless applications. The polygonal wide slot in ground plane widen the frequency range and improve the return loss of antenna. The battery slot and rectangular shape under patch has improved the gain, radiation pattern and antenna bandwidth ranging from 2.08 to 6.64GHz. In the proposed design, fractional bandwidth of 104% has been achieved. The peak gain and radiation efficiency is 5.4 dB and 96%, respectively. The antenna exhibits nearly bidirectional radiation patterns for most of the desired frequencies at the bandwidth range. Therefore, it is suitable for WLAN, WiMAX and other wireless communication services.

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