Bandwidth Improvements Using Ground Slots for Compact UWB Microstrip-fed Antennas

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Abstract— The paper studies the method of using a ground slot for bandwidth improvement of compact ultra-wide band (UWB) antennas with microstrip line feed. Slots of different shapes such as triangular, rectangular, partially circular and hexagonal, placed on the ground plane under the feed line of the radiator are studied for impedance matching. The effects of the slots on the performances of the antennas, in terms of impedance bandwidth, radiation pattern, gain, and efficiency, are studied. Results of simulation tests show that a ground slot with proper dimensions placed under the feed line can improve the impedance matching and hence increase the bandwidth without affecting much the performance of the antenna. Results of studies also show that, by using a hexagonal slot on the ground plane under the feed line, a patch antenna with a compact size of 35 mm × 23 mm can achieve a bandwidth of 3.1–16.3 GHz for $S_{11} < -10$ dB. Moreover, it has a stable omnidirectional radiation pattern across the whole bandwidth and achieves an average gain of 2.8 dBi and an average efficiency of about 88% across the UWB.

1. INTRODUCTION

The planar-monopole antenna, due to its compact size, ease of fabrication and low cost, is one of the most popular structures for the design of UWB antennas [1]. In the designs of microstrip-fed monopole antennas, some strategies such as tapered or stepped feed lines have been used to enhance the impedance matching [2–4]. However, these methods make the calculations of the feed-line dimensions very complicated. A simpler and effective method by cutting a slot on the ground plane under the feed line has been proposed and studied [5–11]. In these studies, rectangular slots were most often used [5–8]. Other shapes such as triangular [9, 10], trapezoidal [11] and "T-Shape" [12] have been also studied. In these studies, different shapes of radiators were used, so it is difficult to say which slot shape is the best choice for UWB antennas. In this paper, attempts are made to find out the best slot shape for the UWB antenna. We present the results of a study on the effects of using different slot shapes on the performance of an UWB antenna, in terms of impedance bandwidth, radiation pattern, gain and efficiency. A compact microstrip-fed monopole antenna with a square radiator and a partial-ground plane is used in our study.

2. ANTENNA DESIGN

The geometry of the microstrip-fed UWB monopole antenna without slot is shown in Fig. 1, which is used as a reference antenna in our study. The antenna is designed on a FR4 substrate with a thickness of 1.6 mm, a dielectric constant of 4.2 and a loss tangent of 0.02. The square radiator printed on one side of the substrate has a length of L_p and is fed by a microstrip line with a length of L_f and a width of W_f. A partial-ground plane with the dimension $L_G \times W$ is printed on the

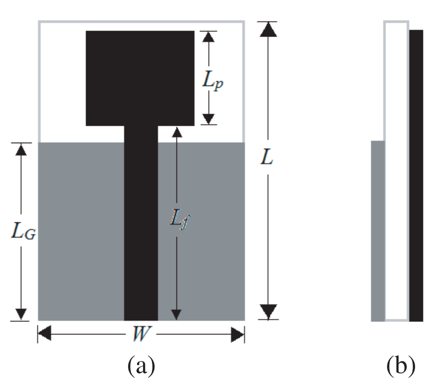

Figure 1: Geometry of reference UWB antenna without slot: (a) front view, (b) side view.

other side of the substrate. The overall antenna occupies an area of $L \times W$. The performance of the antenna is optimized, in terms of maximizing the bandwidth (for $S_{11} < -10\,\text{dB}$) and stabilizing the radiation pattern (omnidirectional radiation pattern), using the EM simulation tool CST. The optimized dimensions are: $L_p = 10\,\text{mm}$, $L_f = 22\,\text{mm}$, $W_f = 3\,\text{mm}$, $L_G = 20\,\text{mm}$, $W = 23\,\text{mm}$ and $L = 35\,\text{mm}$.

To improve the impedance matching of the antenna throughout the UWB, a small slot is cut on the upper edge of the ground plane under the feed line as shown in Fig. 2. Slots of different shapes including: (a) triangular, (b) rectangular, (c) partially circular, and (d) hexagonal shapes, are used in our studies.

3. RESULTS AND DISCUSSIONS

An extensive-simulation study has been carried out to determine the optimal dimensions of the triangular, rectangular, partially circular and hexagonal slots in the antenna of Fig. 2, by maximizing the bandwidth and results are shown in Table 1. With the uses of these dimensions, the simulated $S_{11}$of the antenna without a slot and with different slots are shown in Fig. 3. It can be seen that, without a slot, the antenna has a bandwidth of 3.3–10.3 GHz (a relative bandwidth of 103%) for $S_{11} < -10\,\text{dB}$. However, with the use of a slot, the antenna can have a remarkable increase in bandwidth. The largest improvement is provided by the hexagonal slot, with which the antenna can extend the bandwidth to 3.1–16.3 GHz (136%). The antennas using the circular, rectangular, and triangular slots can also extend the bandwidths to 3.1–15.4 GHz (133%), 3.1–14.9 GHz (131%), and 3.1–14 GHz (127%), respectively. Thus, among the slots studied, the hexagonal slot provides the best impedance matching and the maximum bandwidth.

The influences of the slots on the radiation patterns have also been investigated. Fig. 4 shows the co-polarization radiation patterns of the antennas at 3, 8.5, 10 and 15 GHz in the E- and H-planes. It can be seen that all the antennas have stable omnidirectional radiation patterns in the H-plane throughout the operation band, indicating that adding a slot under the feed line does not affect the radiation patterns in the H-plane. Thus, in applying this method for bandwidth

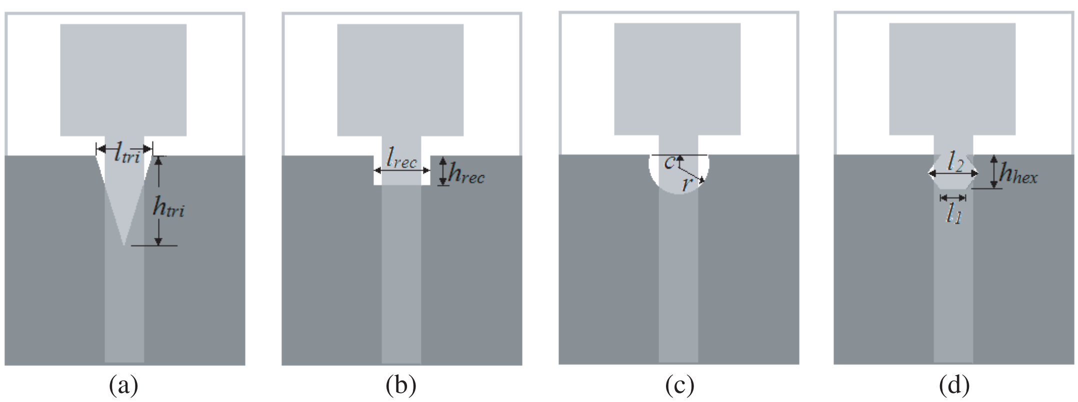

Figure 2: Antennas with different slot shapes: (a) triangular slot, (b) rectangular slot, (c) partial circular slot and (d) hexagonal slot.

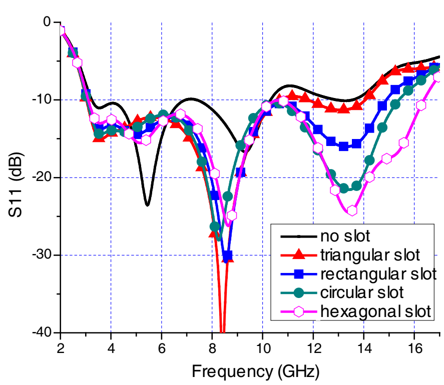

Figure 3: Simulated S_{11} of antennas without slot and with different shapes of slots.

Table 1: Optimized dimension of different slots.

parameter	Triangular slot		Rectangular slot		Partially circular slot		Hexagonal slot		
	l_{tri}	h_{tri}	l_{rec}	h_{rec}	r	C	l_1	l_2	h_{hex}
value (mm)	4	8	3	3.2	2	1.5	1.8	6	2

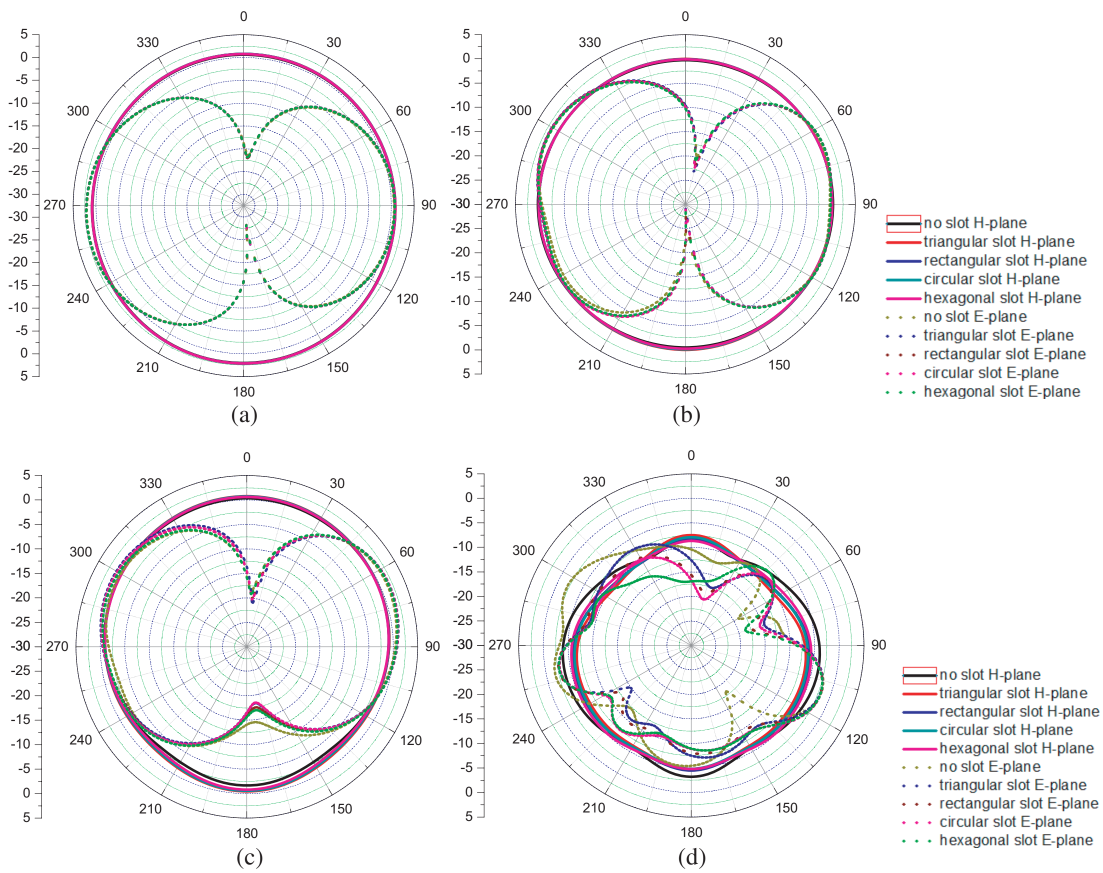

Figure 4: Co-polarization in H- and E-planes: (a) 3 GHz, (b) 8.5 GHz, (c) 10 GHz and (d) 15 GHz.

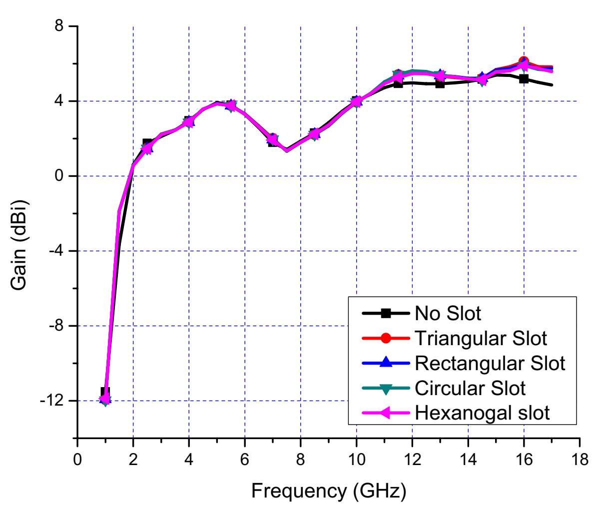

Figure 5: Peak gain of antennas.

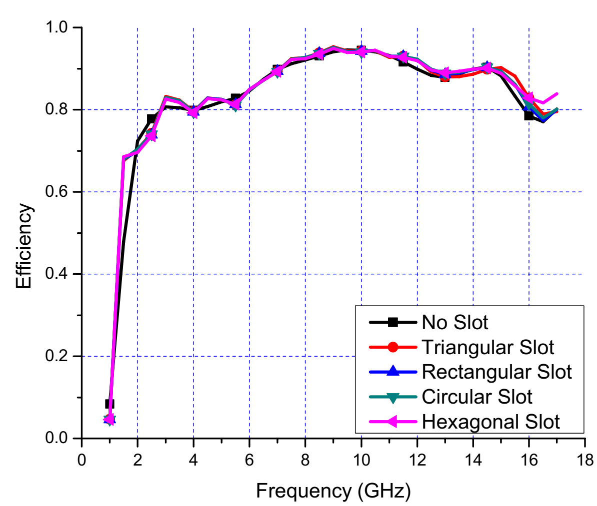

Figure 6: Efficiency of antennas.

improvement, we could firstly design an UWB antenna with a stable omnidirectional pattern and then add a hexagonal slot to improve the impedance matching. This gives antenna designers an additional and independent way to increase the bandwidth of their monopole antennas.

The simulated peak gains and efficiencies of the antennas from 1 to 17 GHz are shown in Figs. 5 and 6, respectively. It can be seen that all of the antennas have almost the same gain and efficiency, so again the slots do not have much effects on the performances throughout the entire operation band. The average gains of these antennas from 3.1to 10.6 GHz are about 2.8 dBi and the average efficiencies are about 0.88.

4. CONCLUSIONS

The method of using a ground slot for bandwidth improvement of a compact UWB planar monopole antenna has been studied. The antenna has a compact size of 35 mm × 23 mm and the small ground slot is placed under the feed line on the ground plane. Triangular, rectangular, partially circular and hexagonal slots have been used for studies by simulation. Results have shown that the slots can improve impedance matching of the antenna with little effect on the radiation characteristics. Among these slots investigated, the hexagonal slot provides the largest impedance bandwidth of 3.1–16.3 GHz for $S_{11} < -10$ dB, with an average gain of about 2.8 dBi and an average efficiency of about 88%.

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