

Design of a Pot-Shaped Monopole Antenna with Dual Band Notched Characteristics for UWB Application

Kwang Yun Mok¹ · Young Chul Rhee¹ · Joong Han Yoon^{2,*}

Abstract

A compact planar microstrip-fed ultra-wideband (UWB) antenna with a dual band-notched for UWB application is presented and analyzed. By inserting a U-shaped slot and inverted U-shaped slot into the pot-shaped radiator, two notched bands are achieved. By optimizing the width and length of the U-shaped slots and inverted U-shaped slot, a desired bandwidth of voltage standing wave ratio (VSWR) less than 2.0 can be achieved, ranging from UWB bands with notched dual bands. The proposed antenna is fabricated on an inexpensive FR-4 substrate with overall dimensions of 28.0 mm × 39.5 mm. The measured results confirm that the proposed antenna covers from 1.775 to over 13.075 GHz with two rejection bands of around 3.325–3.925 GHz and 5.3125–6.025 GHz. In addition, the proposed antenna showed good radiation characteristics and gains in the UWB bands.

Key Words: Dual Band Notched, Pot-Shaped Model, U-Shaped Slot and Inverted U-Shaped Slot, UWB Application.

I. INTRODUCTION

Since its approval for use in communications by the Federal Communications Commission in 2002, the ultra-wideband (UWB) has received substantial attention from both the academic and industrial sectors [1]. UWB applications have become the focus of short range, high speed wireless communication because of its many advantages—high speed data rate, high precision ranging, low power consumption, and great capacity. Research activity on UWB systems continues to grow rapidly, and many different prototypes of UWB antennas have been proposed and developed [2–4]. The antenna plays an important role as a key component that determines the RF performance of the end-product. Therefore, the increasing popularity of UWB communications has created a need for a UWB antenna with a low

profile, low weight, low cost, easy fabrication, the ability to be flush-mounted, and simplicity in structure. Conversely, the frequency range for UWB systems will cause interference with existing narrowband wireless communication systems. As an example, the wireless local area network for IEEE 802.11a operates at 5.15–5.35 GHz and 5.725–5.725 GHz; while the IEEE 802.16 system operates at 3.3–3.7 GHz.

Therefore, compact UWB antennas with dual band-notched characteristics capable of avoiding any potential interference are required. Recently, a number of band-notched UWB antennas have been discussed, and several methods have been used to create antennas with band notched characteristics [5–13]. In particular, pot-shaped patch antennas for wideband application have been studied [14, 15]. Pot-shaped UWB antennas [14] and dual band notched pot-shaped UWB antennas [15] have been researched.

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In this paper, a novel dual band-notched UWB antenna is proposed with a band-notched design process. The proposed antenna is fed by a microstrip feed line. By inserting a U-shaped slot and an inverted U-shaped slot into the pot-shaped radiator and tuning the relevant parameters, two notched band applications are achieved. The dual band-notched antenna is fabricated and experimentally verified. A parametric study is performed by observing the effect of the different geometrical parameters on the performance of the proposed antenna. The measured gain and radiation patterns are presented.

II. ANTENNA DESIGN

Fig. 1 shows the geometrical configuration of the proposed antenna. The antenna is designed and fabricated on a RF4 substrate with a dielectric constant and dielectric loss tangent of 4.4 and 0.02, respectively, and a thickness of 1.0 mm. The total size of the substrate and the ground plane of the proposed antenna are $25.0 \text{ mm} \times 39.5 \text{ mm}$ ($W_1 \times L_1$) and $25.0 \text{ mm} \times 10.0 \text{ mm}$ ($W_1 \times L_7$), respectively. The proposed antenna consists of a pot-shaped radiating patch and $50 \ \Omega$ feed line. The pot-shaped model is composed of a circular shaped radiator with a radius of 10 mm and an ellipses shaped radiator, where the major axis and minor axis of the ellipse is 9.0 mm and 6.3 mm, respectively. The radiating element was placed on the same side as the feeding strip, and the ground plane was placed on the other side of the substrate. The size of the proposed antenna is somewhat bigger than the dimensions given in the published paper. The patch size of the proposed antenna is $28.0 \text{ mm} \times 34.5 \text{ mm}$. The patch sizes in the published papers [7, 10, 12] are $10.0 \text{ mm} \times 16.0 \text{ mm}$, $26.0 \text{ mm} \times 16.5 \text{ mm}$, and $25.0 \text{ mm} \times 25.0 \text{ mm}$, respectively.

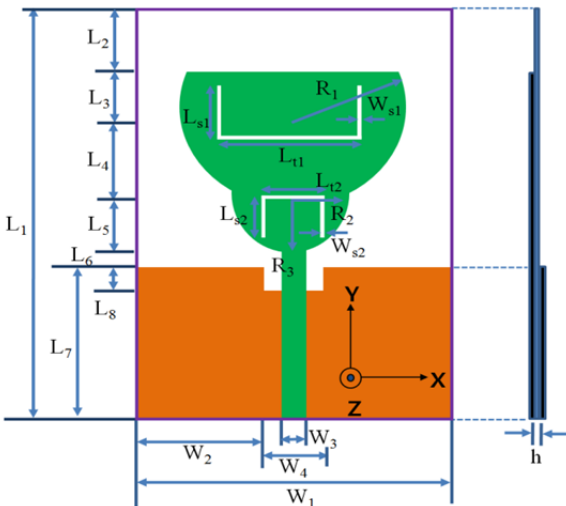


Fig. 1. The configuration of proposed antenna.

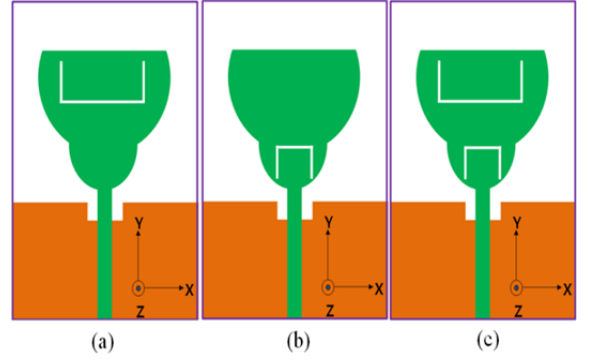


Fig. 2. Design evolution of the proposed antennas: (a) antenna I, (b) antenna II, and (c) antenna III.

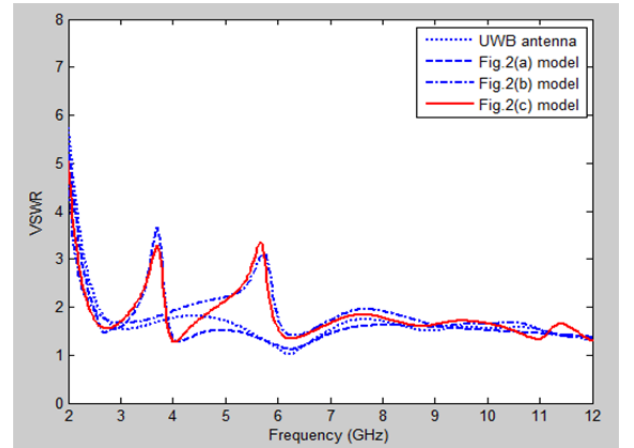


Fig. 3. Simulated VSWR characteristics for the evolution of the proposed antennas shown in Fig. 2.

The geometry for a U-shaped slot in the pot-shaped patch in order to obtain 3.5 GHz band-notched characteristics, an inverted U-shaped slot in the pot-shaped patch in order to obtain 5.5 GHz band-notched characteristics, and the proposed antenna structure are shown in Fig. 2. Voltage standing wave ratio (VSWR) characteristics for the structures shown in Fig. 2 are compared in Fig. 3. As shown in Fig. 3, we insert a U-shaped slot and an inverted U-shaped slot in the pot-shaped patch, and a dual band-notched function can be achieved.

The design of the proposed antenna is in accordance with the described guidelines followed for optimization with the commercially available software Ansoft HFSS version 1.0 (ANSYS Inc., Canonsburg, PA, USA)-a full-wave commercial EM software capable of simulating a finite substrate and a finite ground structure. Parameter studies are conducted to provide more detailed information about the antenna and optimization. By adjusting the lengths, widths, and locations of the U-shaped slot and the inverted U-shaped slot, we can obtain the optimized antenna dimensions. From the simulated results, the VSWR curves for the proposed antenna with various parameters L_{s1} and L_{s2} are given in Figs. 4 and 5.

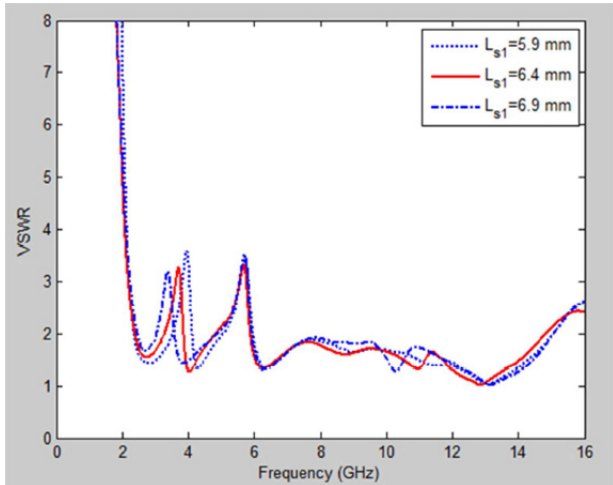


Fig. 4. Simulated VSWR characteristics of the proposed antenna with different values of L_{s1} .

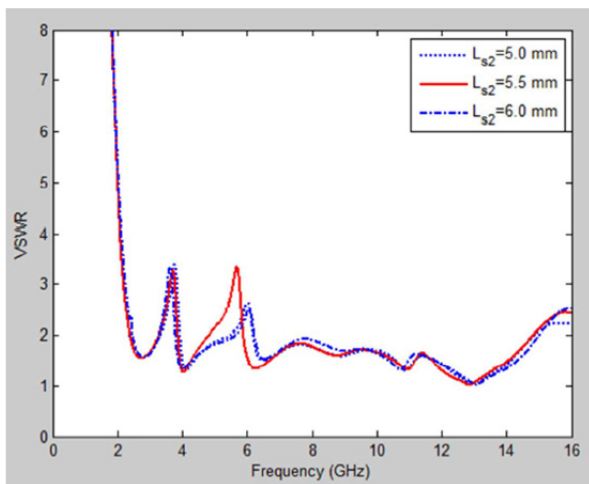


Fig. 5. Simulated VSWR characteristics of the proposed antenna with different values of L_{s2} .

As shown in Fig. 4, the length of L_{s1} has a great effect on the lower notched band. With the L_{s1} increase, the lower notched band of the antenna shifts down, while the higher notched band changes slightly. The results clearly indicate that the notched frequency of the antenna (Fig. 2(a)) can be effectively controlled by adjusting the length of L_{s1} of the U-shaped slot in the pot-shaped radiator. Fig. 5 shows that when the parameter L_{s2} increases, the higher notched band of the proposed antenna clearly shifts, while the lower notched band changes only slightly. The results indicate that the notched frequency of the antenna (Fig. 2(a)) can be effectively controlled by adjusting the length of L_{s2} of an inverted U-shaped slot in the pot-shaped radiator.

The values of the design parameters shown in Fig. 1 were calculated using the optimized Ansoft HFSS. Thus, the dimensions of the proposed antenna were set as follows: $R_1 = 10.0$ mm; $R_2 = 9.0$ mm; $R_3 = 6.3$ mm; $L_1 = 39.5$ mm; $L_2 = 6.5$ mm; $L_3 = 6.5$ mm; $L_4 = 7.5$ mm; $L_5 = 7.8$ mm; $L_6 = 1.2$

mm; $L_7 = 10.0$ mm; $L_7 = 2.0$ mm; $W_1 = 25.0$ mm; $W_2 = 11.0$ mm; $W_3 = 1.5$ mm; $W_4 = 3.0$ mm; $L_{s1} = 6.4$ mm; $L_{s1} = 14.1$ mm; $L_{s2} = 5.5$ mm; $L_{s2} = 6.6$ mm; $W_{s1} = 0.3$ mm; $W_{s2} = 0.3$ mm; and $h = 1.0$ mm. From the simulation results, the impedance bandwidth has the frequency band of 2.46 to over 14.80 GHz with two rejection bands around 3.256–3.925 GHz and 5.125–5.913 GHz.

III. MEASUREMENT

A photograph of the fabricated proposed antenna with dual band-notched characteristics is illustrated in Fig. 6. Fig. 6(a) and (b) show the front and back view of the fabricated

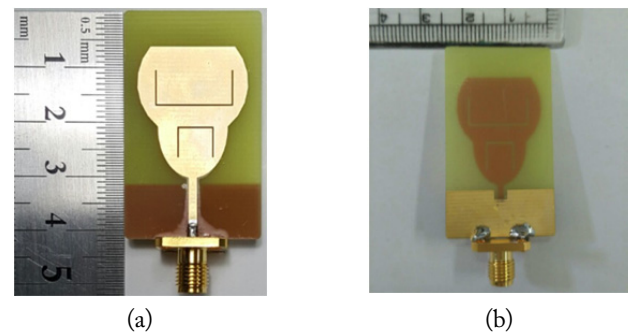


Fig. 6. Prototype of the proposed dual band notched UWB antenna. (a) front view and (b) back view.

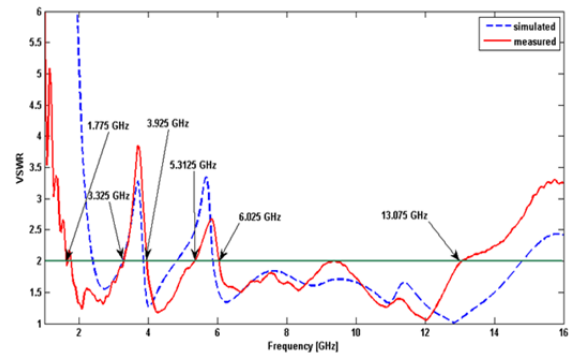


Fig. 7. Simulated and measured VSWR vs. frequencies of the proposed antenna.

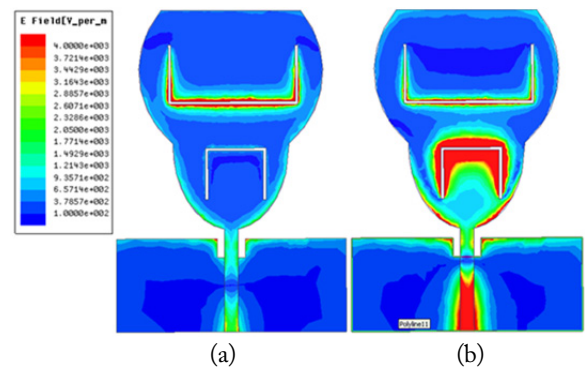


Fig. 8. Simulated surface current distributions at two different frequencies. (a) 3.66 GHz and (b) 5.68 GHz.

antenna, respectively. Fig. 7 plots the simulated and measured VSWR as a function of frequency for the proposed antenna. The VSWR of the proposed antenna is measured using the Anritsu MS4644A vector network analyzer. The measurement demonstrates that the proposed antenna exhibits dual-notched frequency bands of 3.325.2–3.925 GHz and

5.3125–6.025 GHz, while maintaining a wideband performance from 1.775.5 to 13.075 GHz for $VSWR \leq 2$, covering the entire UWB frequency band (3.1–10.3 GHz).

The measured notched band shows an upwards shift from the simulated results. The difference is mainly accounted for by the effect of the SMA and possible numerical errors. As

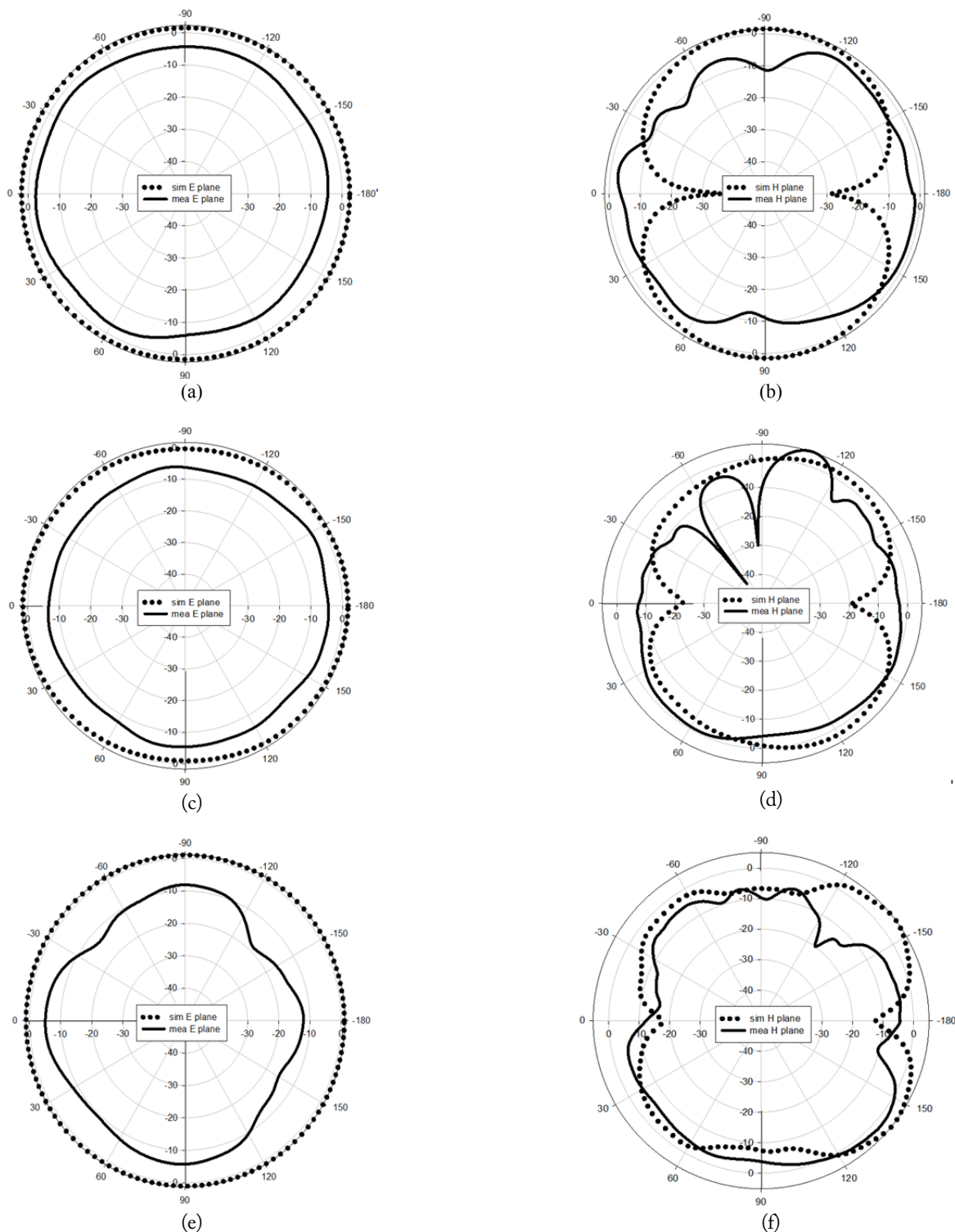


Fig. 9. Radiation patterns of the proposed antenna for the UWB operation frequencies in (a, c, e) the E-plane at 3.1 GHz, 6.1 GHz, 9.1 GHz and (b, d, f) the H-plane at 3.1 GHz, 6.1 GHz, 9.1 GHz, respectively.

the simulation used a waveguide port, and since an SMA connector was used for the measurement, a difference appeared between the measurement and simulation results.

To better understand the band-notched behavior of the antenna, the simulated surface current distributions on the proposed antenna are presented and discussed. Fig. 8 depicts the current distribution of the proposed antenna at 3.66 and 5.68 GHz. It is seen that dense currents are distributed around the U-shaped slots at notch frequencies of 3.66 and 5.68 GHz, which may cause impedance variations in forming the notch bands. At the operating frequency of 3.66 and 5.68 GHz, the current distributions are mostly concentrated on the U-shaped slot and the inverted U-shaped slot in the pot-shaped antenna, causing the notched bands.

The radiation characteristics of the proposed antenna are measured. All the results are tested using ACE. The measured far-field radiation pattern of the proposed antenna at frequencies of 3.1 GHz, 6.1 GHz, and 9.1 GHz in the two principles—E plane (xz-plane) and H plane (yz-plane)—are shown in Fig. 9. It is seen that the radiation patterns in the E-plane are bidirectional radiation for operating at all frequencies, and the radiation patterns in the H-plane as somewhat omni-directional.

Furthermore, Fig. 10 presents the measured peak gain variations against the frequency of the proposed antenna with and without the U slots on the radiating patch. As observed, a sharp gain reduction is obtained at the 3.5 GHz band and 5.5 GHz band. The proposed antenna successfully performed with the rejection in 3.5 and 5.5 GHz notched bands. The gains range from 1.183 to 5.8 dBi over the operating band of 3.1–10.6 GHz, except the 3.3–3.7 GHz band with the lowest point of -3.693 dBi at 3.6 GHz and the 5–6 GHz band with the lowest point of -4.988 dBi at 5.6 GHz.

IV. CONCLUSION

In this article, a simple pot-shaped planar UWB antenna with dual band-notched characteristics has been presented, and its characteristics are investigated. By adjusting the lengths, widths, and locations of a U-shaped slot and an inverted U-shaped slot, we can obtain the optimized antenna dimensions. Furthermore, the results of the studies on the simulated surface current distributions at the dual band-notched frequencies are discussed herein. The fabricated antenna has a frequency band of 1.775 to over 13.075 GHz with two rejection bands of 3.325–3.925 GHz and 5.3125–6.025 GHz, while maintaining a wideband performance from 1.775.5 to 13.075 GHz for $VSWR \leq 2$, covering the entire UWB frequency band (3.1–10.3 GHz). The proposed UWB antenna also exhibits omni-directionality in the H-

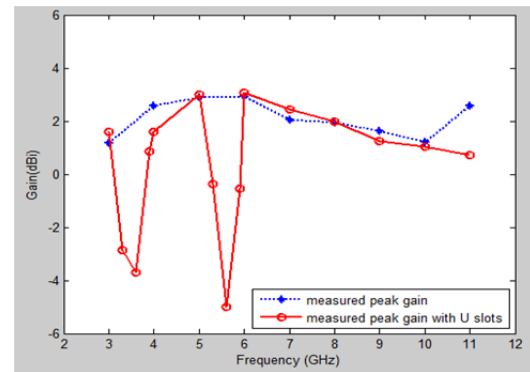


Fig. 10. Measured antenna peak gains for the following operating frequencies.

plane and a monopole-like pattern in the E-plane. The gains range from 1.183 to 5.8 dBi over the operating band of 3.1–10.6 GHz, except the 3.3–3.7 GHz band with the lowest point of -3.693 dBi at 3.6 GHz and the 5–6 GHz band with the lowest point of -4.988 dBi at 5.6 GHz. The compact size and viable antenna characteristics of the presented antenna make it appropriate for UWB system applications.

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