Compact UWB Printed Slot Antenna With Extra Bluetooth, GSM, and GPS Bands

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***Abstract*—A novel compact ultrawideband (UWB) printed slot antenna with three extra bands for various wireless applications is presented. The low-profile antenna consists of an octagonal-shaped slot fed by a beveled and stepped rectangular patch for covering the UWB band (3.1–10.6 GHz). By attaching three inverted U-shaped strips at the upper part of the slot in the ground, additional triple linear polarized bands can be realized covering GPS (1520–1590 MHz), part of GSM (1770–1840 MHz), and Bluetooth (2385–2490 MHz). Simulated and measured results are presented and compared, which shows that the antenna has a stable radiation pattern both at the triple and the whole of the UWB bands.**

***Index Terms*—Compact printed antenna, multiband, slot antenna, ultawideband (UWB).**

I. Introduction

WITH the capability of transmitting ultrashort duration pulses in the ultrawideband (UWB) technology, UWB systems have received great attention for the short-range wireless communication. Based on the high data rate and low power consumption, one can anticipate that UWB systems will be soon used also in conjunction with the portable devices such as mobile handset [1]. Design of a simple, compact, and multifunctional antenna is an important part in the integration of the UWB system with the portable devices since it can reduce the complexity of the receiver and transmitter section.

Recently, more and more research has been carried out to provide simple and compact UWB antennas. Various shapes of monopole antennas—such as a beveled rectangular patch [2] and a circular printed monopole with steps [3]—and various shapes of slot antenna—such as inverted cone slot [4], tapered slot with tuning patch [5], and rectangular slot with coplanar waveguide (CPW) feed [6], [7]—have been reported for a compact UWB antenna.

However, only a few papers have been reported on the integration of the UWB band with other wireless narrow bands. In [8], multiband performance is achieved by employing a single L-shaped slot in the ground plane of a compact circular disc monopole antenna. However, the final structure does not cover the UWB band completely. In [9], an L-shaped strip is attached at the corner of a rhomboidal monopole for integration of the UWB and Bluetooth band. The technique used in that letter highly affects the UWB performance of the antenna. An extra band for Bluetooth is created in [10] by attaching a narrow quarter-wavelength stub to the high concentrated current area in the ground plane. In [11], a fork-shaped monopole is used for integration of a Bluetooth and UWB band. However, in all of these structures, adding other extra bands with the same used technique is probably impossible.

In this letter, a novel compact printed UWB slot antenna with three extra linear polarized bands covering GPS (1520–1590 MHz), part of GSM (1770–1840 MHz), and Bluetooth (2385–2490 MHz) is proposed. The base antenna consists of an octagonal slot fed by a beveled and stepped rectangular patch that covers the UWB band (3.1–10.6 GHz). For generating the three additional bands, while keeping the antenna compactness, three inverted U-shaped strips attached to the ground are incorporated in the upper part of the octagonal slot antenna. Details of designing the proposed antenna with simulations carried out through the software package HFSS and measurement of a fabricated prototype are presented.

II. Antenna Design

The design procedure of the proposed UWB printed slot antenna is illustrated in Figs. 1 and 2. The base antenna, Antenna II, as shown in Fig. 2(a) consists of an octagonal-shaped slot fed by a beveled rectangular patch. This compact base structure can cover the whole of the UWB band. In this antenna, for a better impendence matching over the UWB band, three steps with 0.8 mm length are etched in the upper part of the patch. The patch is fed through a 50-Ω microstrip transmission line. This antenna is etched on a 0.8-mm-thick FR4 substrate with $\varepsilon_r = 4.4$ and dielectric loss tangent of 0.02. The antenna has compact dimensions of 25×28 mm^2.

It is known that over the frequency range of excitation, current is present on the ground plane of the slot antenna. By attaching resonant strips of appropriate length to the ground, one can create additional resonances to the UWB antenna. The position of the strip attachment to the ground provides the impedance matching. Thus, to create three additional resonant frequency bands, three narrow strips of 0.4 mm width are attached to the top of the slot ground, referred to as Antenna III, shown in Fig. 2(b). To have the GPS band, the length of strip 1 should be $L_{t1} = 9.2 + 4.7 + 11.2 + 3.5 = 28.6$ mm. For GSM band, the length of strip 2 should be $L_{t2} = 9.1+4+10.4+0.7 = 24.2$ mm. Ffor Bluetooth band, the length of strip 3 is set at $L_{t3} = 8.9 + 3.3 + 5.7 = 17.9$ mm. The spacing between each of the strips is 0.4 mm.

Each of the extra resonances takes place when the length of the relevant strip is equal to $\lambda_g/4$, in which λ_g is the guided

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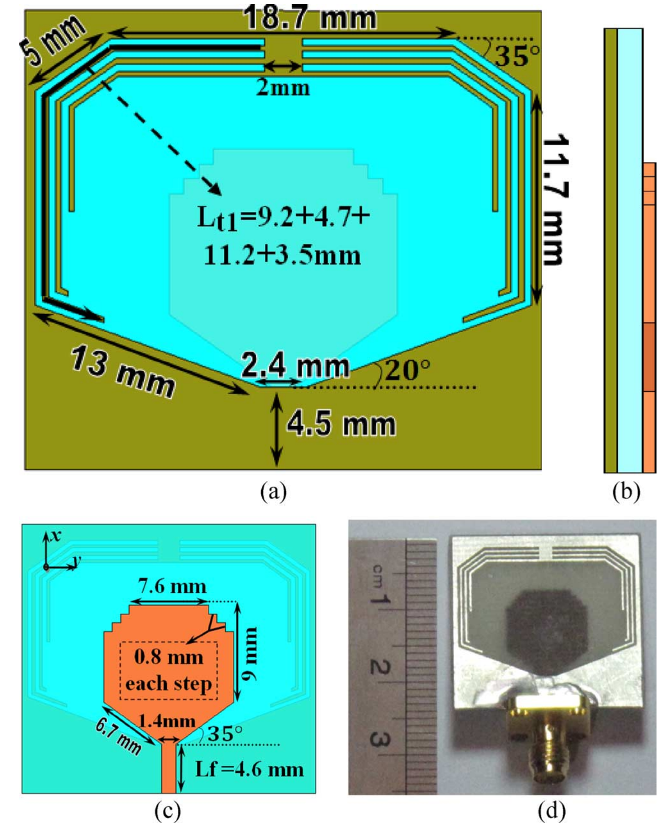

Fig. 1. Antenna I: Configuration of the multiband printed UWB slot antenna with three inverted U-shaped strips. (a) Bottom layer. (b) Side view. (c) Top layer. (d) Fabricated prototype.

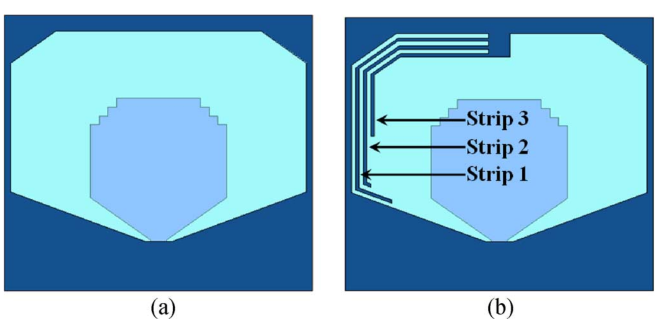

Fig. 2. Configuration of the printed UWB antenna. (a) Antenna II: UWB base antenna. (b) Antenna III: UWB antenna with three added strips in one side.

wavelength at the desired frequency. Thus, the length of each strip can be obtained approximately from the following formula:

$$L = \frac{c}{4f\sqrt{\frac{\varepsilon_r + 1}{2}}}. \quad (1)$$

in which ε_r, c, and f are dielectric constant, the velocity of light in free space, and the center frequency of the desired band, respectively. To have a better impedance matching and a radiation pattern with lower cross polarization, the strips as obtained from (1) are also placed symmetrically on the other side of the patch. The shape of the final strips is in the form of an inverted U as shown in Fig. 1(a). This is referred to as Antenna I. Other parameters of the UWB slot antenna with three inverted U-shaped strips are optimized and are shown in Fig. 1(a) and (c). The fabricated prototype of the antenna is shown in Fig. 1(d).

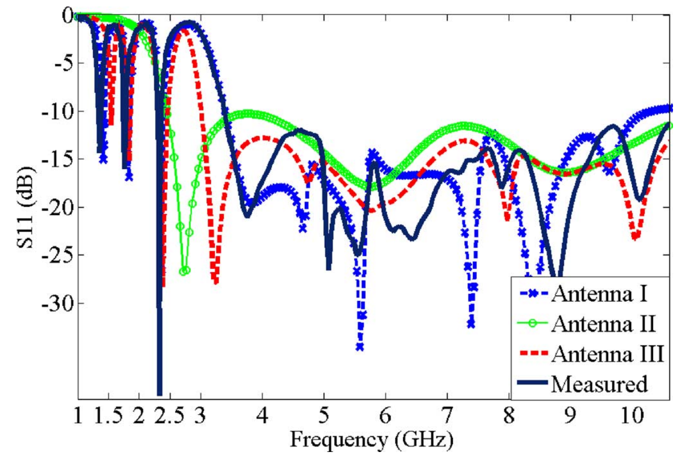

Fig. 3. Simulated reflection coefficient of Antenna I (UWB with three inverted U-shaped strips), Antenna II (UWB), and Antenna III (UWB with added strips in one side). Measured reflection coefficient of Antenna I.

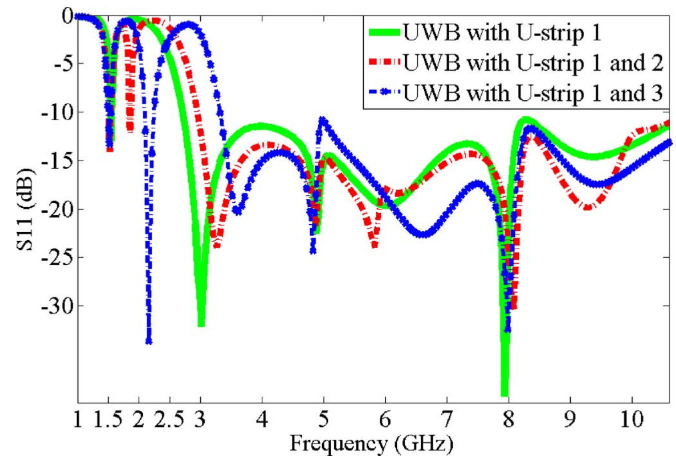

Fig. 4. Simulated reflection coefficient of Antenna I, with different configurations of U-shaped strips.

III. Results and Discussion

The reflection coefficient of the three types of antennas discussed in Section II—Antennas I, II, and III—is shown in Fig. 3. Since the presence of the strips make the surface of the octagonal slot smaller, the UWB starting frequency changes. As a result, the size of the base antenna without the strips (Antenna II) is set larger, effectively covering 2.3–11 GHz. By adding three strips to the base antenna (Antenna III), the three extra resonances would be created. To improve the impedance matching level of the three resonances, similar strips are placed symmetrically on the other side of the patch (Antenna I). As can be seen from Fig. 3, the UWB printed slot antenna with three inverted U-shape strips covers the whole of the UWB band (3.1–10.6 GHz) as well as the three extra linear polarized bands [12].

The measured reflection coefficients of the proposed UWB printed slot antenna with the three inverted U-shaped strips are also compared in Fig. 3. From the measured results, it can be seen that the first band covers 1520–1590 MHz, the

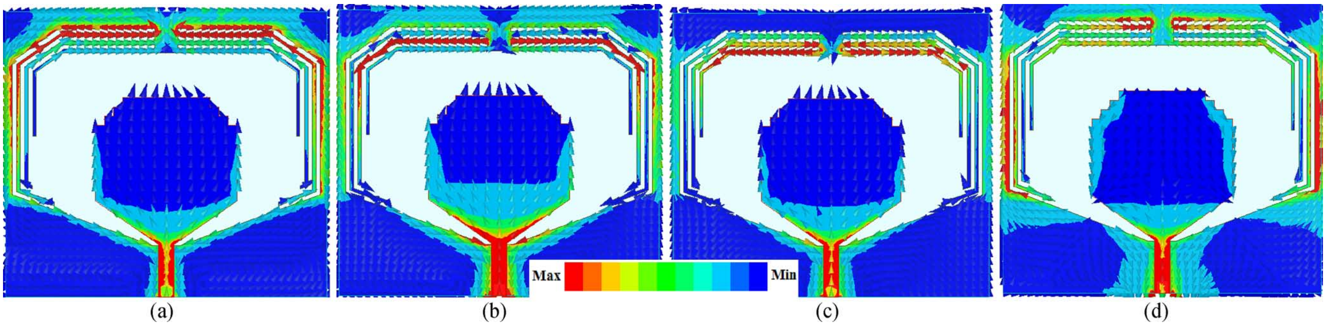

Fig. 5. Simulated current distribution of Antenna I at frequencies of (a) 1.5, (b) 1.8, (c) 2.45, and (d) 4.5 GHz.

second band covers 1770–1840 MHz, and the third band covers 2385–2490 MHz. Thus, the proposed antenna can cover the whole of the GPS and the Bluetooth bands while it covers part of the GSM band (1710–1880 MHz). This limitation of bandwidth over the GSM band means that reduced number of channels would be available for communication.

Fig. 4 shows the reflection coefficient of the proposed UWB printed slot antenna with the presence of different configurations of inverted U-shaped strips. As it can be seen, by choosing the desired inverted U-shaped strips, the desired added frequency bands can be created without affecting the performance of the UWB and other added bands of the antenna.

To better understand the antenna behavior, current distribution on the UWB slot antenna with the three inverted U-shaped strips is presented in Fig. 5. Fig. 5(a)–(c) shows the current distribution of the proposed antenna at the added bands of 1.5, 1.8, and 2.45 GHz, respectively, while Fig. 5(d) shows the current distribution of the proposed antenna at 4.5 GHz in the UWB frequency range. As it can be seen from Fig. 5(a)–(c), the current distribution at 1.5, 1.8, and 2.45 GHz is strong around the strip 1, 2, and 3 respectively. Also, by studying the surface current distribution on the strips at the added bands, it can be seen that the current is maximum at the place of attachment of the strip to ground and is minimum at the other end, confirming the quarter-wavelength behavior of the strip and formula (1). It needs to be said that placing strips symmetrically on the other side of the patch does not increase the length of the current path, while a better impedance matching occurs at the added bands. Thus, (1) can also be used in designing Antenna III.

The effect of the length of the added inverted U-shaped strips is shown in Fig. 6. As it can be seen, by changing the length of each strip, the related extra frequency changes with negligible effect on the other extra bands. Therefore, one can simply add the desired extra frequencies to the UWB band by simply choosing the desired strips length through (1). Other parameters of the inverted U-shaped strips like gap between each strip and width of strips have little effect on antenna performance and are chosen at the optimum value in antenna design.

A study on the effect of microstrip feed length (Lf) on the UWB and added band is presented in Fig. 7. As it can be seen, by changing this parameter from its optimum value, significant effect on the impedance matching of the antenna especially in the UWB performance takes place.

The measured co- and cross-polar E- and H-plane radiation patterns of the proposed slot antenna at three passband

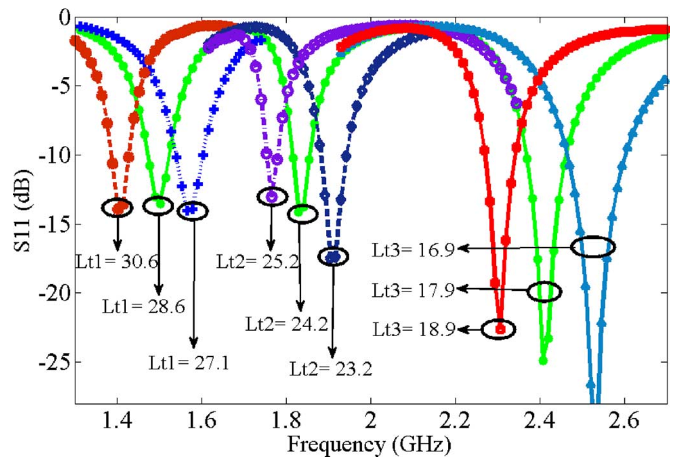

Fig. 6. Simulated reflection coefficient of Antenna I with different inverted U-shaped strip length at the added bands. All dimensions are millimeters.

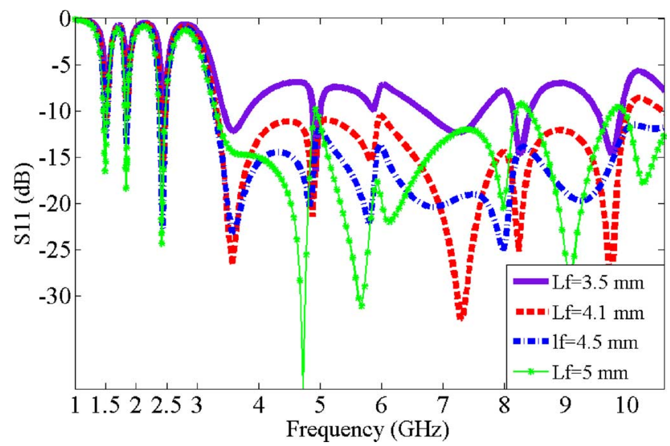

Fig. 7. Simulated reflection coefficient of Antenna I, with different feed length Lf.

frequencies of 2.45, 4.5, and 6.5 GHz are shown in Fig. 8. As it can be seen, the antenna has excellent cross-polarization level at the added bands of 2.45 GHz and has a stable omnidirectional radiation pattern in H-plane (yz-plane), while the antenna E-plane (xz-plane) radiation pattern is almost bidirectional in the whole of the UWB and added bands.

The measured peak gain of the proposed antenna over various frequencies is shown in Table I.

Group delay is an important parameter in the design of the UWB antenna since it gives the distortion of the transmitted

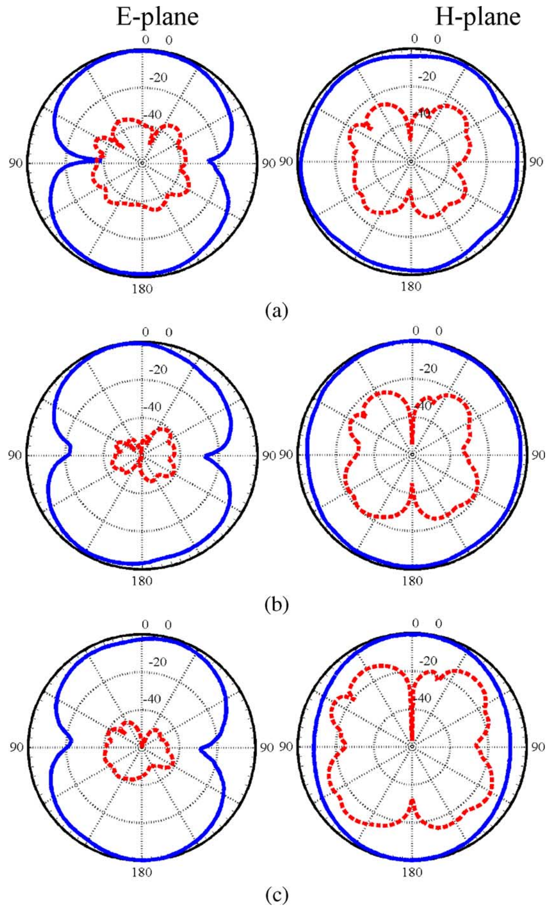

Fig. 8. Measured E- and H-plane radiation patterns of the proposed UWB printed slot antenna with three inverted U-shaped strips at (a) 2.45, (b) 4.5, and (c) 6.5 GHz frequencies. Solid line represents copolarization, and dashed line represents cross polarization.

TABLE I
MEASURED PEAK GAIN OF THE ANTENNA

Frequencies	1.5	3	5.5	7.5	9.5	11
***Peak Gain* (dB)**	-6	-4	2.5	2.5	5	4

pulses in the UWB communication. For a good pulse transmission, group delay should be almost constant in the UWB band. The simulated group delays of the proposed antenna for both side-by-side and face-to-face configurations are shown in Fig. 9. In each case, two similar UWB antennas that are placed 35 cm apart are used. As it can be seen, the maximum variation of the group delay for the face-to-face configuration is less than 0.55 ns, while that of the side-by-side case is less than 0.85 ns. This confirms that the proposed UWB antenna is suitable for UWB communication.

IV. CONCLUSION

The design of a UWB slot antenna with three additional practical bands for the whole GPS and Bluetooth bands and part of the GSM band has been presented in this letter. The UWB slot

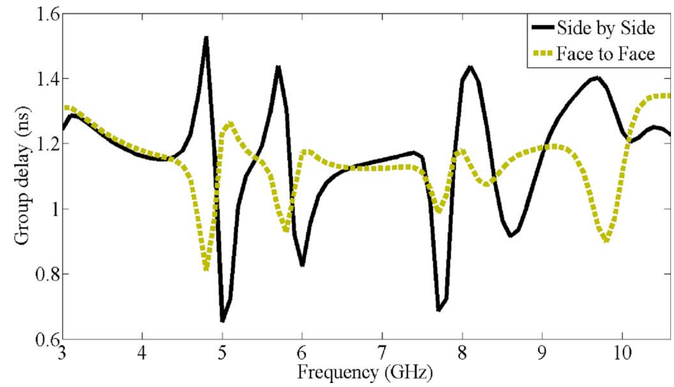

Fig. 9. Simulated group delay of the proposed UWB antenna with three inverted U-shaped strips for side-by-side and face-to-face configurations.

antenna has an octagonal shape with compact structure. By attaching three strips of quarter-wavelength to the upper part of the slot ground, three extra bands are created. To have a better impedance matching over the added bands, these quarter-wavelength strips are also placed symmetrically on the other side of the fed patch that form inverted U-shaped strips. The measured results of the fabricated antenna show stable radiation patterns over the whole of the UWB band as well as the extra bands. Also, almost constant group delay is achieved. Thus, the proposed antenna is a good candidate for future multifunctional portable devices.

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