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A Simple Printed Ultrawideband Antenna With a Quasi-Transmission Line Section

Ching-Wei Ling and Shyh-Jong Chung

***Abstract*—In this communication, we propose a simple and compact printed ultrawideband (UWB) antenna. The antenna is mainly composed of a monopole section and a quasi-transmission line section. The input signal from the feed line first passes through the line section then enters the monopole. The quasi-transmission line section provides different functions as the operating frequency changes. It serves not only as an impedance matching circuit but also a main radiator, which leads to the UWB performance of the antenna. The resonance mechanisms across the full band are described, followed by a thorough study of the antenna's geometrical parameters.**

***Index Terms*—Monopole antennas, quasi-transmission line, ultrawideband (UWB) antennas.**

I. Introduction

With the rapid development of the wireless communications, many systems now operate in two or more frequency bands. The ultrawideband (UWB) antennas, which are usually, designed using single antenna structure with broadband operation, become attractive for the benefits of simpler structure than multi-band designs with several narrow-banded elements. Here, the UWB antennas mean those with relative impedance bandwidth larger than 25% [1]. Besides, according to the regulations released by Federal Communications Commission, one of the UWB systems has been allocated to the frequency band of 3.1 to 10.6 GHz [2] for the merits of large capacity of data and high speed data transmission rate. Thus, there is a growing demand on antenna design for a brief structure with wideband operation, both for the integration usage of multi-mode multi-frequency systems and for an UWB system.

There are many related studies to improve the impedance bandwidth published in the open literature [3]–[8]. Among these antennas, there is usually an important factor of a small gap between the fat monopole and the ground plane edge for impedance matching, especially in the high frequency range. Due to appropriate current paths across the full band provided by the antenna structure, the wideband operation is thus achieved [3]–[6]. On the other hand, using parasitic elements, for providing additional current paths [7] and applying double or triple feeds to the main antenna structure also can improve the impedance bandwidth [8].

In this communication, a new antenna configuration, containing a conventional printed thin-wire monopole, in addition to a quisi-transmission line section for the ultrawideband application is presented. The quasi-transmission line section provides impedance matching or antenna radiation at different frequency bands. By properly designing the parameters of this quasi-transmission line section, several current resonances with continuous frequencies can happen in the antenna structure, which thus makes the whole antenna possessing ultrawideband performance.

Manuscript received July 01, 2008; revised March 03, 2009. First published August 07, 2009; current version published October 07, 2009. This work was supported in part by the National Science Council, Taiwan, under Contract NSC 96-2752-E-009-003-PAE.

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Digital Object Identifier 10.1109/TAP.2009.2029376

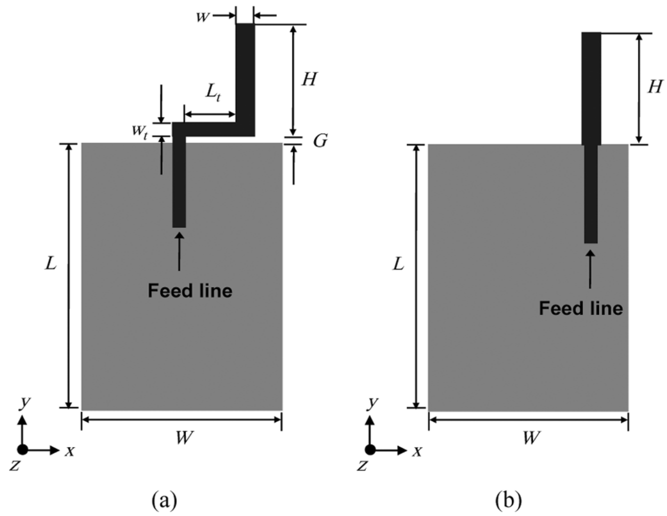

Fig. 1. Geometries of (a) the proposed antenna and (b) a conventional monopole antenna.

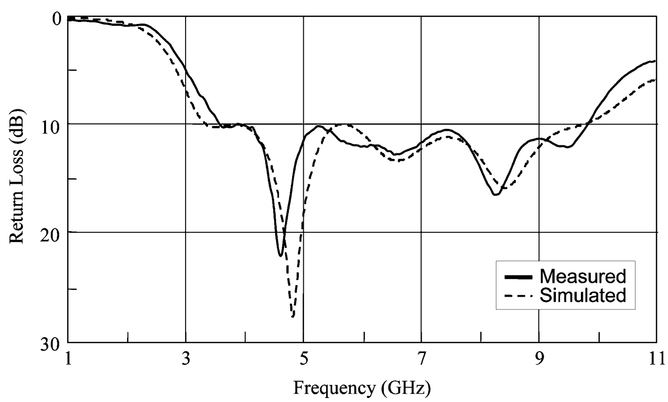

Fig. 2. Measured and simulated return loss of the proposed antenna with $H = 12.4$ mm, $w = 2$ mm, $L_t = 4$ mm, $w_t = 1.5$ mm, and $G = 0.6$ mm. The ground size $W \times L = 20$ mm × 27 mm.

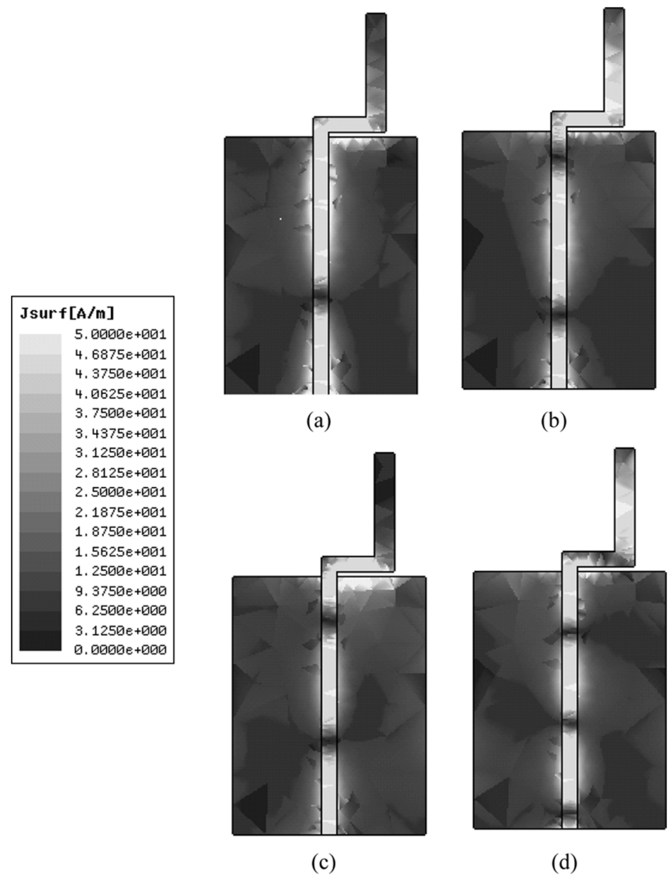

Fig. 3. Simulated current distributions of the proposed antenna at (a) 3.66, (b) 4.83, (c) 6.46, and (d) 8.43 GHz.

Fig. 1(a) shows the geometry of the proposed antenna. It consists of a vertical monopole section and a short horizontal quasi-transmission line section. The quasi-transmission line section is formed by a parallel metal wire and the ground plane with a small gap of G. The metal wire has a length of L_t and a width of w_t. The height and width of the monopole section are denoted as H and w, respectively, and the size of the ground plane is $W \times L$. A 50 Ω microstrip line of 1.5-mm width is connected to the antenna as the feed line. The antenna is implemented on an FR4 substrate of dielectric constant 4.5 and thickness 0.8 mm. Fig. 1(b) is the geometry of a conventional printed monopole antenna for comparison.

II. Resonances of the Antenna

In this section, the resonance mechanisms of the proposed antenna are described according to the simulated current distributions on the antenna structure. They can also be checked from the parameter study in Section IV. The antenna is simulated using the Ansoft High Frequency Structure Simulator (HFSS) [9].

Fig. 2 illustrates the simulated and measured return losses of the proposed antenna. The simulated result shows a 10-dB return loss bandwidth of 98.6% from 3.33 to 9.80 GHz, which is very close to the measurement (93.2% from 3.57 to 9.8 GHz). And from the simulation, the antenna exhibits four resonances, with resonant frequencies at 3.66, 4.83, 6.46, and 8.43 GHz, which sustains the full operation band. The locations of the four resonances are also close to the measured ones (3.67, 4.65, 6.29, and 8.35 GHz). A best return loss of 22 dB is measured at the second resonant frequency. In general, the simulated result agrees well with the measurement.

Fig. 3(a)–(d) shows the current distributions at the four resonant frequencies, respectively. At the first resonant frequency [Fig. 3(a)], the current on the vertical monopole section is weak as compared to that on the quasi-transmission line section. However, as will be shown later, the quasi-transmission line section at this frequency behaves as a series inductor, thus not corresponding to the antenna radiation. Although not obvious in the figure, it is actually the currents on the two sides of the ground plane contributing to the antenna radiation. It means that the ground plane is the main radiator at the present resonant frequency. This can be doubly checked in Section IV when one changes the ground size to see the variation of the resonant frequency.

At the second resonant frequency [Fig. 3(b)], the vertical monopole section has the strongest current as compared to other portions of the proposed antenna. And the current vanishes at the open end and becomes larger when moving toward the connection point of the monopole and the quasi-transmission line section, which is a current distribution similar to that on a typical quarter-wavelength monopole antenna [Fig. 1(b)]. It is thus evident that at the second resonant frequency of 4.83 GHz, the monopole section is the main radiator of the proposed antenna and functions as a quarter-wavelength monopole antenna.

As for the third resonant frequency (6.46 GHz), as shown in Fig. 3(c), the current is mainly distributed on the quasi-transmission line section, surrounding the transmission line gap G. The current vanishes near the

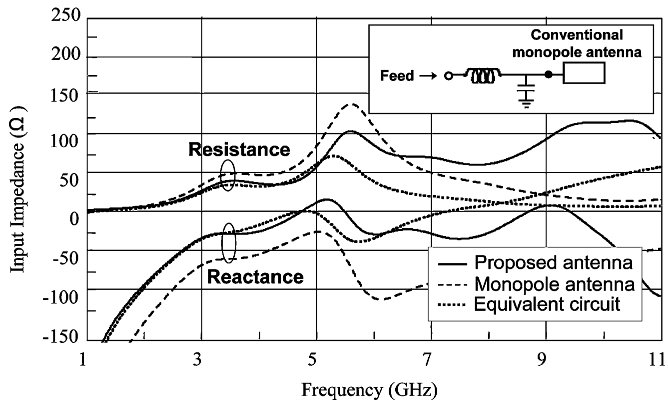

Fig. 4. Comparison of the input impedances of the proposed antenna, the conventional antenna, and the equivalent circuit. The geometric parameters are the same as given in Fig. 2. The equivalent circuit has a series inductance of 1.3 nH and shunt capacitance of 0.14 pF.

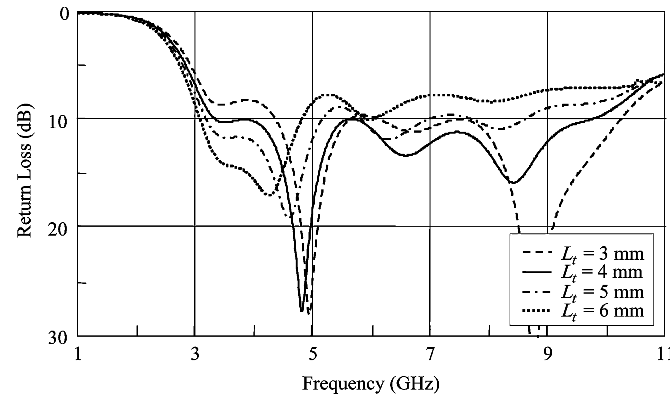

Fig. 5. Simulated return losses for the proposed antenna of various length L_t of the quasi-transmission line section. Other geometric parameters are the same as given in Fig. 2.

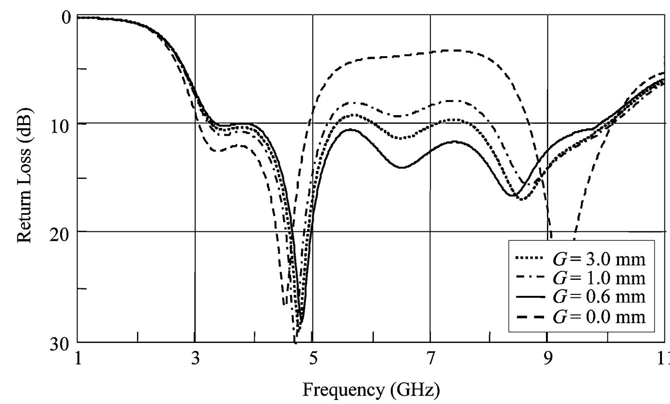

Fig. 6. Simulated return losses for the proposed antenna of various gap G. Other geometric parameters are the same as given in Fig. 2.

right end of the line section and is a maximum at the left end. This current distribution is like that of a quarter-wavelength open slit antenna. Thus, the quasi-transmission line section plays a role as a resonant slit antenna, which is the key contributor of the antenna radiation at the third resonant frequency.

Finally, for the fourth resonant frequency of 8.43 GHz, the proposed antenna has a current distribution as shown in Fig. 3(d). The vertical monopole section has a strong current with a maximum at the midpoint and nulls at both ends. It is clear that a half-wavelength resonance is formed on this vertical monopole section. The monopole section is again the main radiator of the proposed antenna at this resonant frequency, and behaves as a half-wavelength monopole antenna.

III. Effect of the Quasi-Transmission Line Section

Fig. 4 compares the input impedances of the proposed antenna (solid lines) and the convention monopole antenna (dashed lines). It is seen that the impedance behaviors of the two antennas have similar variation trends when the frequency varies under 5 GHz. The proposed antenna has an input resistance smaller but close to that of the monopole antenna, and possesses a more inductive input reactance. Therefore, it can be modeled as a conventional monopole antenna in series with an inductor. This means that the quasi-transmission line section in the proposed antenna serves as an inductor at the lower frequency range. The inset figure shows the equivalent circuit model of the antenna. Since electric charges may accumulate at the bend formed at the connection point of the monopole and quasi-transmission line sections, a small shunt capacitance is added. The simulated input impedance of the equivalent circuit model is shown as the dotted lines in Fig. 4. (The values of the inductance and capacitance are obtained by curve fitting). It is obvious that the results agree very well with the input impedance of the proposed antenna for frequency lower than 5 GHz. It can thus be concluded that, the quasi-transmission line section provides a series inductance for canceling the capacitive input reactance of the monopole antenna due to insufficient monopole length at the lower frequency, thus improving the impedance matching of the proposed antenna.

As for frequency higher than 5 GHz and near 6.46 GHz, according to the simulated current distribution in Fig. 3(c), the primary antenna current, which corresponds to the antenna radiation, is located around the quasi-transmission line section. Thus, the line section in this frequency range is no longer a circuit element but plays the role of a quarter-wavelength slit radiator. Finally, for frequency near the last resonance (8.43 GHz), as stated earlier, a current null appears at the right end of the quasi-transmission line section, forcing a half-wavelength resonance at the vertical monopole section of the proposed antenna. From the simulation, if one increases the length of the quasi-transmission line section, it is found that the current null will move into the line section, extending the resonant length of the monopole current, and thus resulting in a lower resonant frequency. It seems that the quasi-transmission line section in this frequency range acts as a current buffer for the resonant monopole section, and has the function like a quarter-wavelength impedance transformer, which transfer the high input impedance of the end-fed half-wavelength monopole antenna to the 50 Ω feed line impedance.

IV. Parameters Analysis and Radiation Patterns

Fig. 5 shows the simulated frequency response of the return loss for various lengths L_t (3, 4, 5, 6 mm) of the quasi-transmission line section. It is first observed that the third resonant frequency decreases as the length is increased, since the quasi-transmission line section behaves as a quarter-wavelength slit antenna for this resonance. For the first two resonances, the line section provides the inductance for impedance matching. The increase of the length would raise the inductance and thus alter the matching condition. Notably, the second resonant frequency decreases quite obviously as the increase of the length. This can be explained from Fig. 4 that, when L_t increased, the input resistance curve of the equivalent circuit model remains unchanged and has a value near 50 Ω, while the corresponding input reactance curve will be raised due to the increase of the equivalent inductance. The zero-crossing frequency of this reactive curve would thus move toward the lower frequency, thus causing the second resonant frequency

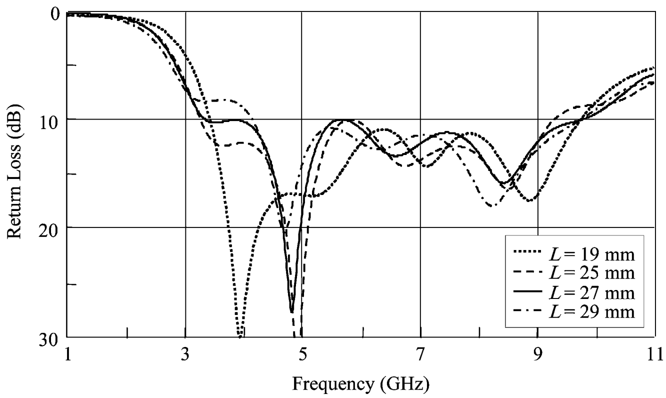

Fig. 7. Simulated return losses for the proposed antenna of various length L of the ground plane. Other geometric parameters are the same as given in Fig. 2.

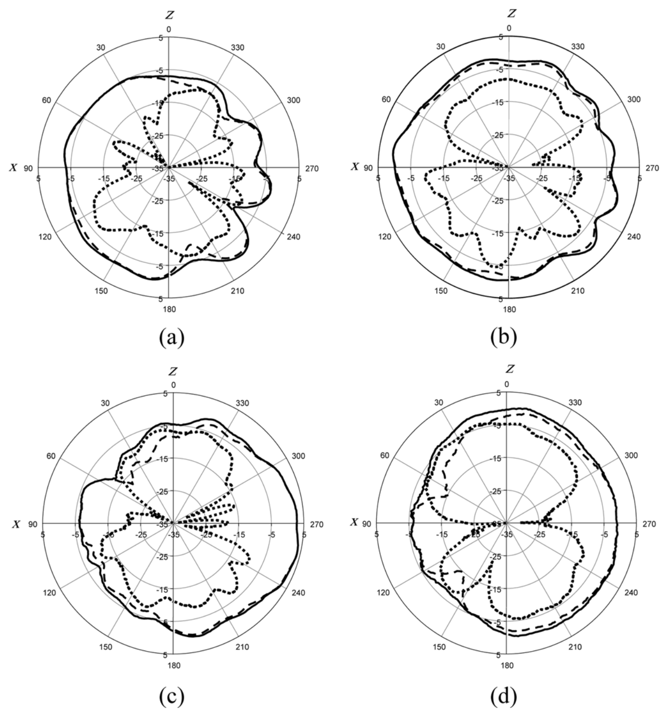

Fig. 8. Measured radiation patterns at (a) 3.67 GHz, (b) 4.65 GHz, (c) 6.29 GHz, and (d) 8.35 GHz. (solid line: $E_{\rm total}$; dashed line: $E_{\rm phi}$; dotted line: $E_{\rm theta}$). The geometric parameters are the same as given in Fig. 2.

changed as shown in Fig. 5. Lastly, one observes that the fourth resonant frequency decreases with the increase of L_t, which is, as mentioned earlier, the result due to the resonant length extension of the half-wavelength monopole current.

Fig. 6 depicts the simulated return losses for various gap widths G (3.0, 1.0, 0.6, 0 mm) of the quasi-transmission line section. Similar to the influence of w_t, the gap variation primarily affects the quasi-transmission line impedance and thus the impedance matching of the antenna. However, the frequency behavior alters dramatically when $G =$ 0 mm. This is because that at this value, the gap in the quasi-transmission line vanishes and the original slit antenna at the third resonance no longer exits, leading to the drastic impedance mismatch from 6 to 8 GHz.

Finally, the effect of the ground plane size is considered. The ground plane of a small antenna is actually an important portion of the antenna, since the induced current on it may have significant contribution to the radiation field as compared to other parts of the small antenna. Fig. 7 depicts the results of varying the ground plane length L (29, 27, 25, 19 mm) with the width W fixed at 20 mm. It can be observed that the change of L affects all the four resonances especially the first one. The smaller the length is, the higher the first resonance is and the better impedance matching can be achieved. Even when the ground length is shrunk to 19 mm, the four resonances still appear apparently and cover over a wide frequency range of 10-dB return loss from 3.43 to 9.73 GHz.

Fig. 8(a)–(d) show the measured radiation patterns in the xz-plane at the four resonant frequencies, respectively. The measured peak gains (average gains) are correspondingly -0.07 dBi (-3.75 dBi), 0.66 dBi (-1.70 dBi), 4.02 dBi (-1.52 dBi), and 0.44 dBi (-2.06 dBi) at the four frequencies. It is noticed that the third resonance (quarter-wavelength slit antenna) at 6.29 GHz exhibits a higher antenna gain than other ones.

V. Conclusion

A simple and compact printed ultrawideband antenna has been proposed and analyzed. It has been demonstrated that the quasi-transmission line section in the proposed antenna structure not only serves as an impedance matching circuit but also a main radiator in the appropriate frequency range, which leads to the appearance of four continuous resonant modes and thus yields to the ultrawideband performance. The measured results agree well with the simulation ones, with a peak gain of 4.02 dBi and a 10-dB return loss fractional bandwidth of 93.2% from 3.57 to 9.8 GHz.

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