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A COMPACT INDUCTIVELY LOADED MONOPOLE ANTENNA FOR FUTURE UWB APPLICATIONS

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Abstract—A novel inductively loaded monopole for future ultra-wide-band (UWB) applications is presented. The antenna is compact and of small size (16 mm × 20 mm × 0.8 mm), and offer a very simple geometry suitable for low cost fabrication and straight forward printed circuit board integration. More specifically, the impedance matching of the classic printed inductively loaded monopole is improved by employment of the tapered microstrip feed line between K-connector and the printed monopole. By using this technique, impedance bandwidth ($S_{11} < -10$ dB) from 3.03 GHz to over 40 GHz is obtained. Measured and simulated return loss curves are provided along with radiation patterns and gains, as a function of frequency. Compared to the recently reported UWB antennas, the presented antenna have smallest size, widest bandwidth, and simple configuration to realize the application in UWB communication systems. Furthermore, symmetric radiation patterns and satisfactory gains make the presented antenna a suitable candidate for practical UWB applications.

1. INTRODUCTION

The Federal Communication Commission (FCC) allocated the frequency band 3.1 to 10.6 GHz for Ultra-Wide-Band (UWB) system [1], which provides an excellent opportunity with low cost, low complexity, low power consumption etc. for short-range high-speed indoor and outdoor data communication. Owing to these

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advantages, UWB communication has been widely used in radar and miniature laptop applications. In the future, it can also be used in a wireless body area network (WBAN) as well as a wireless personal area network (WPAN). To match these applications or network technologies, antennas is designed specifically for UWB have become more and more attractive in recent years. However, the design of low profile, compact antennas for UWB applications is still a major challenge. An adaptive antenna is required to achieve sufficient bandwidth to cover the entire UWB along with exhibiting stable radiation characteristics.

Several antennas have been reported in recent years [2–25]. These designs have various monopole structures, such as rectangular [2], holly-leaf-shaped [3], semi-circle [4], triangular [11], two step tapered [14], etc. and circular disc [15] monopole antennas. Some of these UWB antennas do not have simple structure (i.e., the radiators is etched on a substrate and placed vertically 0.5 mm above the ground plane [16]) and are not suitable to be integrated with associated UWB electronics. And the typical feeding techniques include slotted structures [17, 18, 20], CPW feeds [21, 22], and simple microstrip lines [23, 24, 25]. Antenna operation is generally limited within the FCC defined UWB frequency range for these antenna designs.

However, with increasing demands for improved performances, higher bit rate transmission speeds and the desire for synonymous operation with several techniques, there may be the need for new and future UWB wireless schemes. Antenna operation could thus be required to function beyond the 10.6 GHz upper frequency band limit currently allocated by the FCC. One main design goal for these new UWB antenna is a good $50\,\Omega$ impedance match over the desired operating BW. Fortunately several techniques have been reported in the literatures and presented concept may prove to be helpful. Techniques include tapered microstrip line [26], and microstrip transitions line [27]. In addition, other important antenna design goals include miniaturization, minimal dispersion effects and minor group delay variations, constant gain values as a function of frequency, good impulse response in the time domain, and in some cases, general omni-directional radiation behavior.

In this paper, a novel compact planar monopole antenna with enhancement impedance matching beyond 40 GHz is presented. The antenna is comprised of a simple tapered microstrip feed line and an inductively loaded monopole. By employing tapered microstrip line between K-connector and printed inductively loaded monopole, the $S_{11} < -10\,\text{dB}$ bandwidth can be extended beyond 40 GHz. And by adding the inductive load, a compact size of $16\,\text{mm} \times 20\,\text{mm} \times 0.8\,\text{mm}$

antenna is obtained, which can be considered as one of the smallest size and the widest bandwidth UWB antennas found in the open literatures. The presented antenna is compared with some recently reported UWB antenna from open literatures in Table 1.

Table 1. Comparison between presented and recently reported UWB antennas.

Literature	Pass Band	Dimensions
[5]	$3.5 \sim 12\,\text{GHz}$	$28\,\text{mm} \times 24\,\text{mm} \times 1.6\,\text{mm}$
[15]	$3 \sim 10.6\,\text{GHz}$	$26\,\text{mm} \times 24\,\text{mm} \times 1.6\,\text{mm}$
[26]	$1.08 \sim 27.4\,\text{GHz}$	$124\,\text{mm} \times 120\,\text{mm} \times 1.5\,\text{mm}$
[27]	$3.5 \sim 31.9\,\text{GHz}$	$35\,\text{mm} \times 30\,\text{mm} \times 0.8\,\text{mm}$
[28]	$3 \sim 11\,\text{GHz}$	$34\,\text{mm} \times 27\,\text{mm} \times 0.8\,\text{mm}$
[29]	$3.1 \sim 11.45\,\text{GHz}$	$28\,\text{mm} \times 14.5\,\text{mm} \times 0.8\,\text{mm}$
[30]	$3 \sim 11.2\,\text{GHz}$	$24\,\text{mm} \times 22\,\text{mm} \times 1.6\,\text{mm}$
[31]	$2.82 \sim 13.95\,\text{GHz}$	$30\,\text{mm} \times 36\,\text{mm} \times 0.4\,\text{mm}$
This paper	$3.03 \sim 40\,\text{GHz}$	$20\,\text{mm} \times 16\,\text{mm} \times 0.8\,\text{mm}$

2. ANTENNA DESIGN

The topology of the presented antenna composed of a tapered microstrip feed line and an inductively loaded monopole. It is a top loaded antenna that is implemented with Rogers Duroid 5880 board material. The latter has a relative permittivity $\varepsilon_r = 2.2$, loss tangent $\tan\delta = 0.009$, 17 µm thickness electrodeposited copper, and 0.762 mm thickness. The top and side views of the presented antenna are shown in Fig. 1. The antenna overall size is $20\,\text{mm} \times 16\,\text{mm}$, and it is fed by a tapered microstrip line to achieve a 50Ω input impedance when connected by a K-connector to the source. The radiating portion of the antenna associated with the microstrip feed line is on one side (front) of the substrate, the conducting ground plane is on the other side (back).

The original UWB antenna operating at higher frequencies for the simple microstrip feed line is generally limited to around 10 GHz. To improve matching, the tapered microstrip feed line with proper parameters is replaced with the simple feed line, and the impedance bandwidth of the presented antenna can be extended beyond 40 GHz. It should be mentioned that other feed line structures were investigated by the authors, but the presented tapered microstrip line configuration

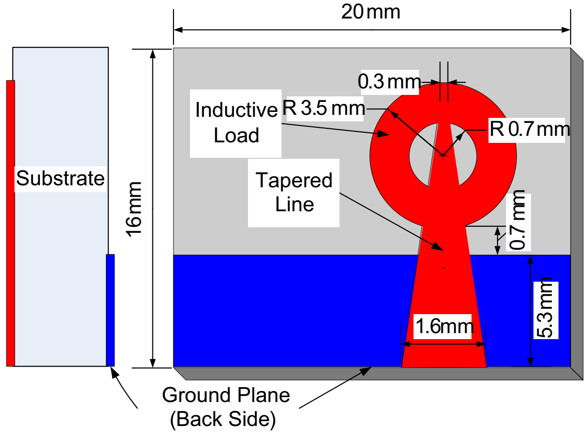

Figure 1. Geometry of the presented UWB antenna.

offered a very low cost solution for the simple antenna designs, while also offering good performance values in terms of 50Ω impedance matching and radiation behaviors. Essentially, the dimensions of the tapered microstrip line are optimized by completing a parametric analysis, while maintaining the width of the input feed line, the inductively loaded monopole, and the characteristics of the utilized substrate.

Following the idea introduced in [32], the inductive load is employed to satisfy the requirement of reducing the size of presented antenna. The load with loop-shaped is printed at the top of the monopole. The added inductive load can offer an extra inductive reactance, and the capacitive reactance of monopole is exactly cancelled at the reduced resonant frequency. As a result, the size reduction of the monopole is achieved.

3. RESULTS AND DISCUSSION

The simulations have been conducted using the High Frequency Structure Simulator (HFSS) version 13. The conduct is modeled as a copper considering its finite conductivity of 5.8×10^7 Siemens/m. The presented antenna is fabricated, and tested in a calibrated anechoic chamber using Agilent E8363C Vector Network Analyzer (VNA). The simulated and measured return losses of the structure are shown in Fig. 2. It is seen that the presented antenna exhibits a wideband performance from 3.03 GHz to beyond 40 GHz (> 171.83%) for $S_{11} < -10$ dB. Reasonably agreements between the measured

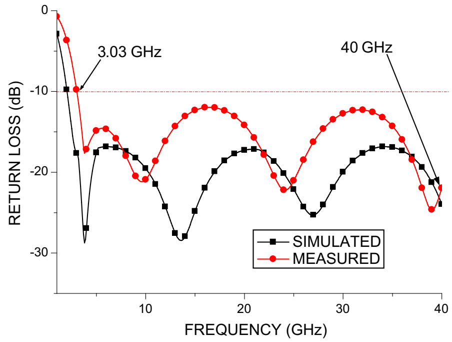

Figure 2. Simulated and measured return losses of the presented UWB antenna.

and simulated results are observed. Deviations may be attributed to substrate variations over frequency, fabrication tolerances, feed connector misalignment, and difficulty in modeling the metal thickness near the ground planes, the radiating portions, and the tapered microstrip line edges due to the fabrication process. Regardless, the measured and simulated results are in agreement and this suggests that the simple tapered microstrip feed line can improve the 50 Ω impedance bandwidth of classic monopole antennas.

Figure 3 shows the current distributions at 6 GHz, 14 GHz, 25 GHz, and 33 GHz on the presented antenna, respectively. In monopole antennas, both the monopole radiator and ground plane contribute to radiating fields. The surface current distribution in Fig. 3(a) shows that the large surface current flows in vertical direction in the feed line and the central of ground plane, and there is a little current around the ground plane. Therefore, radiation patterns of the 6 GHz are nearly omni-directional with negligible cross-polar component. With the increasing of frequency, more complex current distributions are also shown in Figs. 3(b) to (d). It is indicated that the radiation patterns are split at the higher frequency of the presented antenna bandwidth.

Radiation pattern measurement is also completed for the presented antenna in the calibrated anechoic chamber. The results of measured for four resonant frequencies of 6 GHz, 14 GHz, 25 GHz, and 33 GHz are shown in Figs. 4 and 5. It can be observed that at the lower frequency of 6 GHz, the radiation pattern in the H-plane is omni-directional with low cross polarization values. At higher frequencies of 14 GHz and 25 GHz, the radiation patterns are roughly the same as that of monopole antenna. At the highest frequency of 33 GHz, the

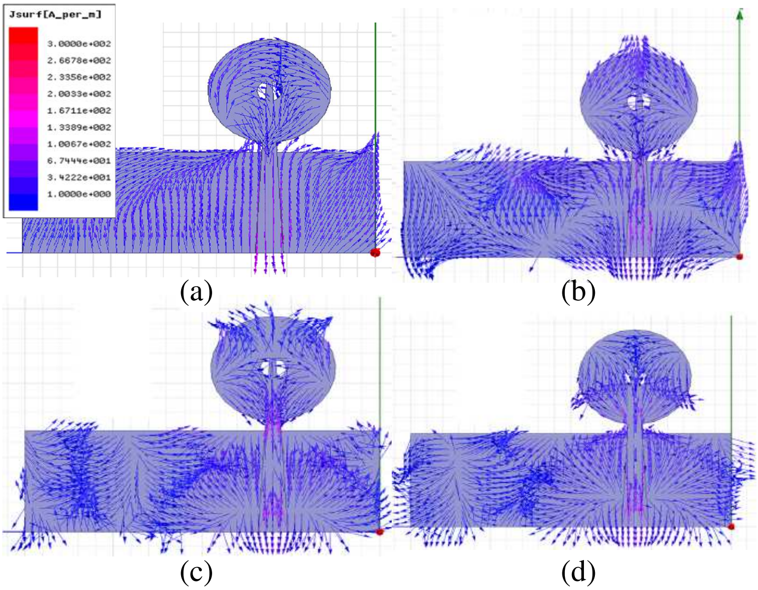

Figure 3. Simulated surface current distribution at (a) 6 GHz, (b) 14 GHz, (c) 25 GHz, and (d) 33 GHz of the presented UWB antenna.

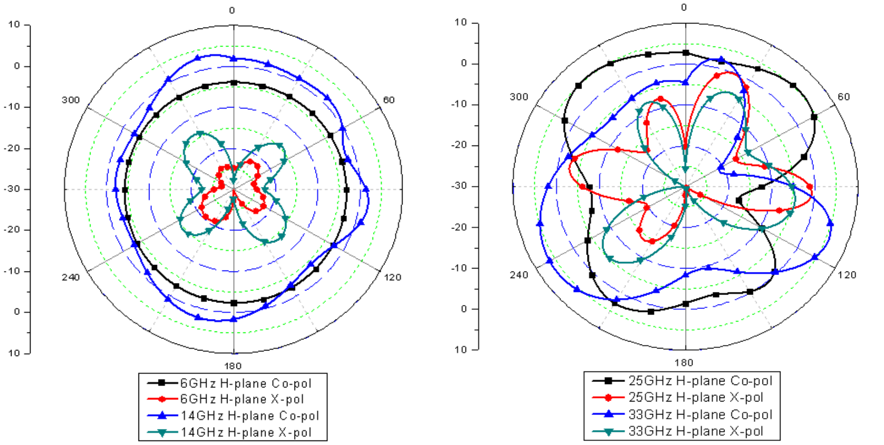

Figure 4. Measured *H*-plane radiation patterns of the presented UWB antenna at 6, 14, 25, and 33 GHz.

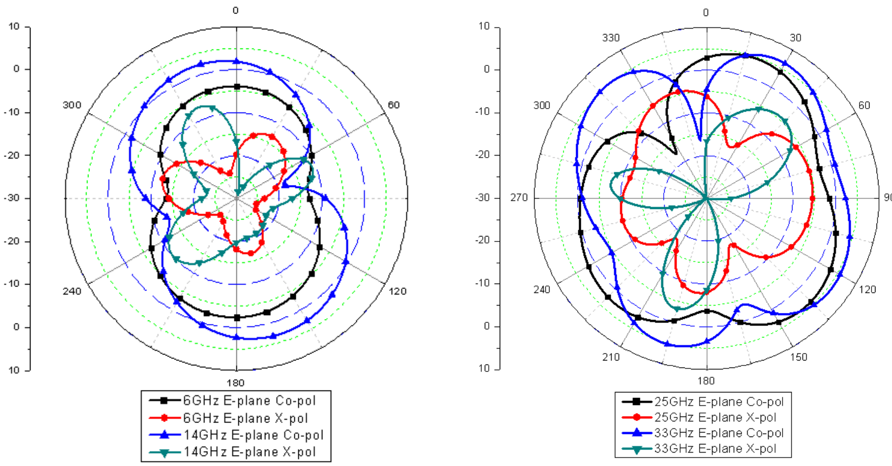

Figure 5. Measured E-plane radiation patterns of the presented UWB antenna at 6, 14, 25, and 33 GHz.

nulls are observed in both E-plane and H-plane, and the radiation patterns become directional. The results indicated that analysis of the current distribution is in accordance with the variation trends of the radiation patterns. In addition, the cross polarization isolations are observed in a high level at lower frequencies, and are decreased obviously in both E-plane and H-plane at 33 GHz. This phenomenon may explain by the radiated far field originating from the main current distributions, which is discussed in above section. And it also may due to the dimensions of the antenna structure are large in comparison to the free space wavelength at 33 GHz ($\lambda_0 = 9$ mm).

Finally, the realized gains are measured and simulated from 3 GHz to 40 GHz, with the step of 1 GHz, and the peak gains of each discrete frequency are plotted in Fig. 6. It can be concluded that the experimental results are in relatively good agreement with the simulated realized gains. As frequency increases, the electrical dimension of the presented antenna also increases linearly. And the gains increasing are seen from Fig. 6. It can be seen that the antenna gain is about $-3 \sim 1$ dBi at $3 \sim 6$ GHz, and quickly increases to 3 dBi at 8 GHz, and remains around $3 \sim 5$ dBi from 8 GHz to 40 GHz. Generally speaking, the measured and simulated gains are similar to those presented in [25–28] over most parts o the bandwidth.

It can be concluded from Figs. 3 to 6 that the presented antenna has the same performance as the antennas reported in [3–31] in entire operation band besides lower gain values in lower frequencies and lower

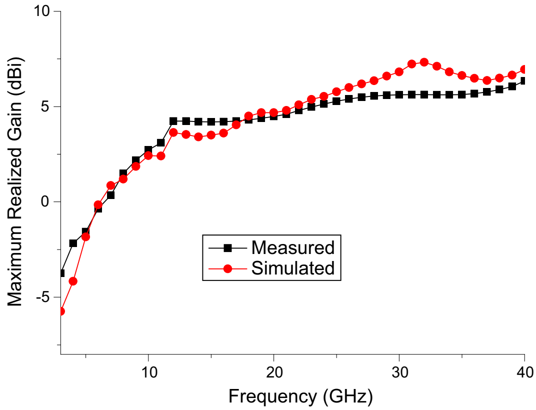

Figure 6. Maximum measured realized gain in E-plane of the presented antenna.

cross polarization isolations in higher frequencies. These disadvantages mainly are attributed to the smaller size of the presented antenna. The technique for size reduction determines that the directions of the current over the driver and load are opposite. This fact takes to the possibility of reducing the radiation field, and as a result, diminishing the antenna gain.

It should be mentioned that antenna measurement are difficult to complete in radiation patterns due to the possible interference and positioning of the metallic tower and measurement cable. Absorber also placed on the metallic antenna tower in an effort to minimize any unwanted interference.

4. CONCLUSION

A novel UWB monopole antenna with very compact size of 20 mm × 16 mm × 0.8 mm and extremely wide band from 3.03 GHz to beyond 40 GHz is presented in this paper. Inductive load and tapered microstrip feed line are employed for size reduction and band enhancement, respectively. Therefore, the presented antenna has smaller size and wider band than the antennas presented in literatures [2–31]. Furthermore, the measurement results indicated that the presented antenna also have simple structure, acceptable gain values and radiation patterns, and these advantages make the presented antenna a suitable candidate for practical UWB applications.

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