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Design of New Compact Ultra-Wideband Microstrip Antenna for MIMO application

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Abstract
A new planar microstrip Ultra-wideband antenna for multi-input-multi-output (MIMO) applications is proposed. The presented antenna has a very compact size of 15 × 13 mm^2 which is printed on a cheap substrate of FR-4. The reflection coefficient and radiation patterns of the antenna are measured and presented. Different configurations of array of the antenna for MIMO application are also studied.

Keywords: Ultra Wideband (UWB), Very Compact, Microstrip antenna

INTRODUCTION

After allocation of the frequency band of 3.1-10.6GHz (UWB) for commercial use by the FCC (Federal Communication Commission) [1], Ultra wideband systems have received wonderful attraction in wireless communication. Microstrip antennas because of offering antennas with low cost, low profile, light weight and ease of fabrication are popular. In addition, compatibility with printed circuit board (PCB) technology making it possible to integrate the antenna with the RF circuits on the same board. These features make it very renown for wireless communications systems. Meanwhile, growing research activity is being focused on application in multi-input-multi-output (MIMO) systems. Consequently, a number of planar monopoles with different geometries have been experimentally characterized [2–4]. Suitable UWB antennas must cover FCC definition for the indoor and handheld UWB applications, have electrically small size, and hold a reasonable impedance match and omni-directional patterns over the entire band. In Figure 1 the equivalent circuit model for radiation element of UWB antenna has been designed. Other types of antennas, except UWB, usually are modeled in the form of radiation resistance; on condition that antenna has impedance matching exactly. Meanwhile, due to broad bandwidth of UWB antennas, mentioned model cannot be always correct and it should be modeled like superposition of some resonant frequencies [5]. For simplicity of calculation, usually only the real part of the Impedance is considered. Using Equation (1), the values of parameters RLC can be calculated by simulated resonant frequencies and numerical methods in multi-step.

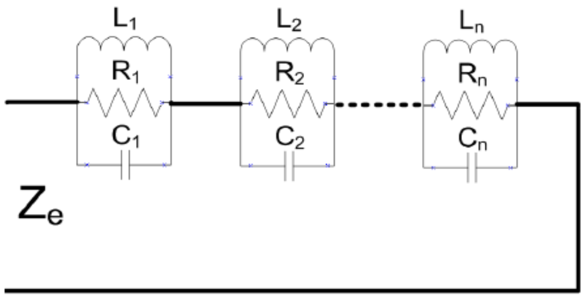

Fig. 1. The equivalent circuit model of UWB antenna

$$\mathbf{R_e} = \sum_{k=1}^{n} \frac{\mathbf{R_k}}{1 + \mathbf{R_k} \cdot \left(\frac{1}{\mathbf{L_k} \cdot 2\pi f} - \mathbf{C_k} \cdot 2\pi f\right)^2} \qquad (1)$$

Unfortunately, because of large bandwidth of UWB band, there is the interference between various narrowband communication systems with UWB band. The most important of them are the frequency bands of Wide Local Area network (WLAN) (5.15–5.35, 5.725–5.825 GHz), Worldwide Interoperability for microwave access (WiMAX) (3.4-3.69, 5.25-5.85 GHz), and ITU Band (8.025-8.4 GHz). To destroy the interference problem, many UWB antennas with various band-notched properties have developed [6–12]. In this manuscript, two monopole antennas are presented; the former an UWB antenna without notch and the latter a microstrip-Fed UWB antenna with triple band-notched characteristics. Both of the antennas were successfully fabricated. The simulated results show reasonable agreement with the measured results. Section II describes the antennas design, discussions on results is presented in Section III followed by conclusive comments and further scope in Section IV. Two-element arrays of such antennas in four different configurations for MIMO applications are analyzed and the results of the pair that provides the lowest mutual coupling are given.

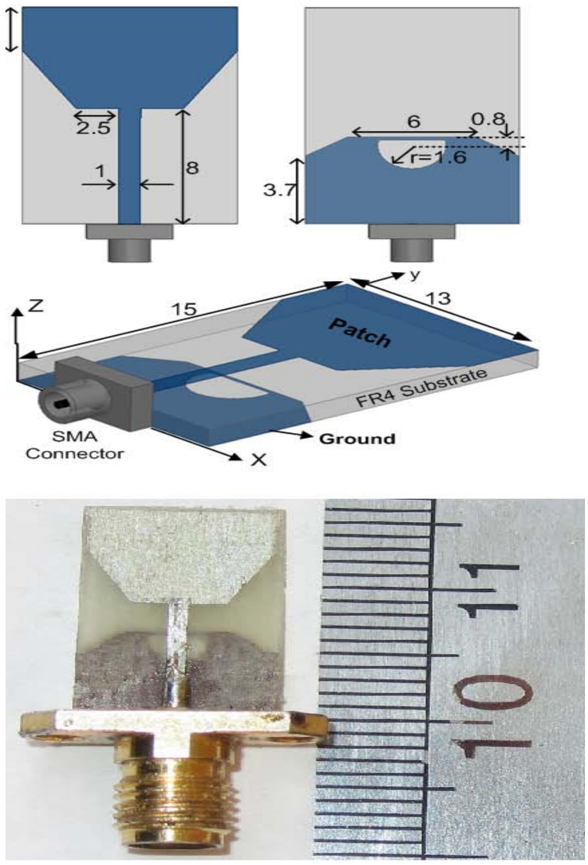

Fig. 2. Configuration and photograph of the fabricated antenna

ANTENNA STRUCTURE AND DESIGN

UWB Antenna without notch

The presented monopole antenna fed by a microstrip line, which geometry and photography of the fabricated antenna are shown in Figure 2. The antenna consists of a simple hexagonal patch and a partial ground which the both of its edges have been etched. Using a semi-circular slot in a different position is new technique to increase the bandwidth. According to it, the semi-circular slot has not been situated on the upper edge of the ground traditionally, but it is located bottom and toward center of the ground. In addition, size of the proposed antenna is 15×13 mm^2.

UWB antenna with triple-band notch function

The overall structure of the second antenna with notch is like earlier, however the set of differences are observed by it. Accordingly, size of the antenna has been decreased to 15×10 mm^2. Furthermore, to create triple notches three slots on the patch and ground are etched which a slot line with length of $\lambda g/2$ is on the patch and two other L-shaped slots with lengths of $\lambda g/4$ are on the ground, too. Besides, Figure 7 illustrates both of the configuration and photo of the fabricated antenna with triple notches. These advantages make the antenna one good candidate for UWB applications. Both of the antennas are printed on an FR-4 substrate with thickness of 1mm and dielectric constant of 4.4 which is connected to a 50Ω SMA connector for signal transmission.

RESULTS AND DISCUSSIONS

UWB Antenna without notch

In this section, simulated and measured results of the proposed monopole antenna are presented. Note that ansoft high frequency simulation structure (HFSS) based on the finite element method (FEM) [13] is used to optimize the presented design. As mentioned before, the proposed antenna used a novel technique to increase the bandwidth. This technique uses a semi-circular slot which is caused to enhance the bandwidth. Figure 3 illustrates reflection coefficient curves of the antenna for the three cases of the antenna without the semi-circular slot, with the semi-circular slot on the upper edge the ground (old method), and proposed antenna. It is obvious that reflection coefficient of the antenna for the case of with semi-circular slot become better on the upper band with creating a resonant frequency at nearly 16.3 GHz and it causes final frequency of bandwidth reaches up to 18.3GHz. As expected before, the measured result has a good agreement with simulation.

The measured gain of the antenna is exhibited in Figure 4. The minimum gain is appeared at the initial frequencies due to compact size of the antenna, but the maximum gain is at frequency 12GHz with value 3 dBi.

The key in the UWB antenna design is to obtain a good linearity of the phase of the radiated field because the antenna should be able to transmit the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency. Ideally, when the phase response is strictly linear, the group delay is constant (2).

$$\text{group delay} = -\frac{d\theta(w)}{dw} \tag{2}$$

As depicted from the Figure 5, the group delay variation of the proposed antennas at the resonant frequencies with respect to other frequencies is more. In spite of it, the group delay variation is less than 0.7ns over the frequency band from 2 up to 16GHz which ensure us pulse transmitted or received by the antenna will not distort seriously and will retain its shape. Therefore, the proposed antenna is suitable for modern UWB communication systems.

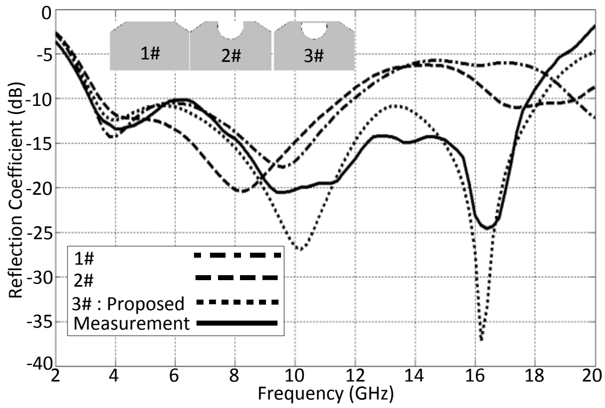

Fig. 3. Measured and simulated reflection coefficient of the antenna.

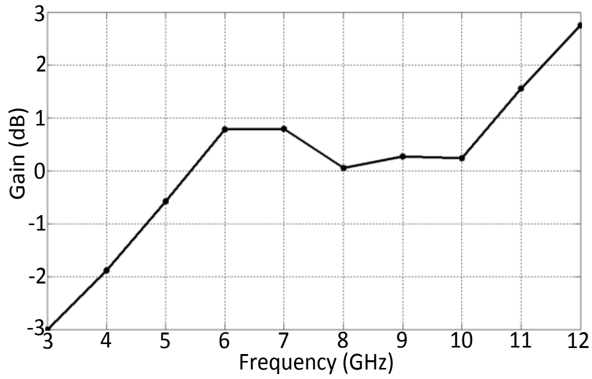

Fig. 4. Measured gain versus frequency for the proposed antenna.

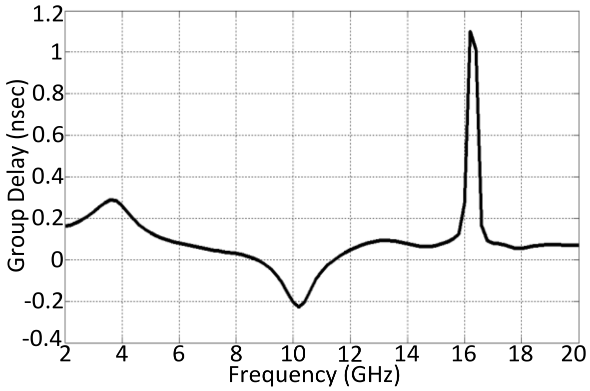

Fig. 5. Group delay versus frequency for the proposed antenna without notch.

Array Structures of UWB antenna without notch for MIMO Applications

This antenna element can be arrayed for use in MIMO applications. The performance of an antenna array suitable for MIMO applications is based on various parameters such as mutual coupling and radiation pattern. Based on the four possible configurations that any two such monopole antennas can be arranged beside each other. Figure 6 illustrates the relevant simulated S-parameters. In each case, the spacing between array elements is set at 15 mm (λ/10 of the lowest frequency band) [3, 4]. From Figure 6 can be seen that position and intensity both of the resonances have been decreased in reflection coefficient (s11) of the array structure of Figure 6(d) while in the rest of them are nearly similar. It is also obvious that s21 or mutual coupling in Figure 6(b) is more than three other figures.

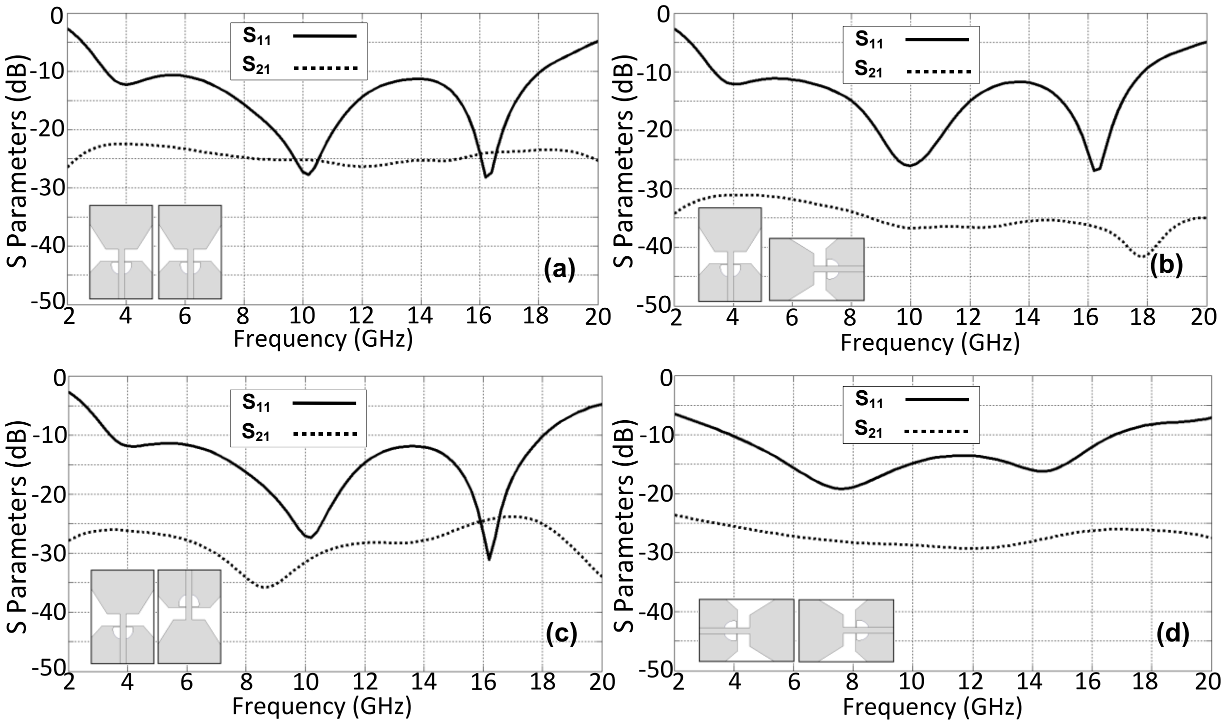

Fig. 6. (a)–(d) Simulated S-parameters of the MIMO configured proposed antenna without notch for different arrangement of two elements beside

UWB antenna with triple-band notch function

To filter the interference bands of WiMAX, WLAN, and ITU is used slot line with length of λg/2 (4) on the patch and two L-shaped slots with lengths of λg/4 (5) on the ground.

$$\varepsilon_{re} = \frac{1+\varepsilon_r}{2} \tag{3}$$

$$L = \frac{\lambda_g}{2} = \frac{300}{2f(GHz)\sqrt{\varepsilon_{re}}} \tag{4}$$

$$L = \frac{\lambda_g}{4} = \frac{300}{4f(GHz)\sqrt{\varepsilon_{re}}} \tag{5}$$

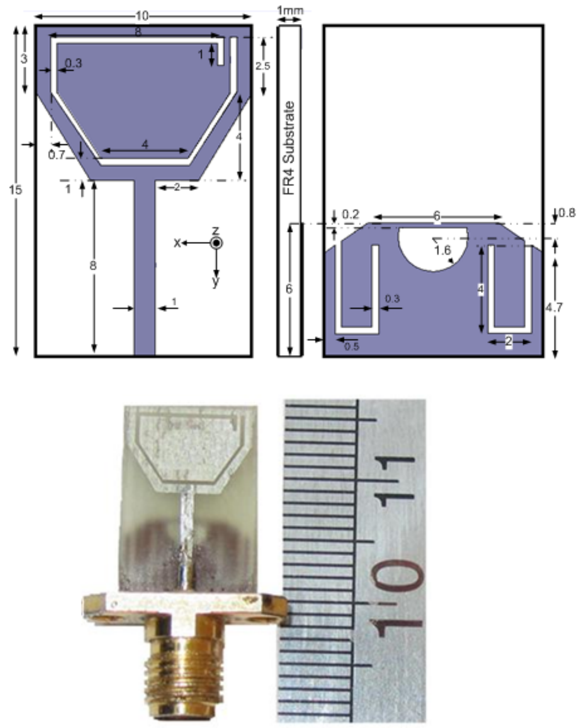

Fig.7. Configuration and photography of the very compact antenna.

The configuration and photo of the antenna with triple notches are shown in Figure 7. As it is apparent, size of the antenna as compared with the antenna without notch is lower with dimension of 15×10mm^2. Simulated current distribution on the patch and ground at three frequencies of 3.5, 5.5, and 8.2 GHz are shown in Figure 8. According to it, slots play important roles to create the triple notches. However, it also leads to a disadvantage, i.e., when this type of antenna is integrated with printed circuit board, the RF circuit cannot be very close to the ground plane. Regarding to Figure 8, slot line on the patch causes to create notched bands in both of WIMAX and ITU. The notch on the ITU band is because of excitation of the second-order mode slot line at almost 8 GHz. It can also be concluded that main factor of notch on WLAN band at central frequency of 5.5 GHz are two L-shaped slots. Meanwhile, the reason of using two L shaped slot instead of one slot on the ground is because of increasing VSWR value on the notched band. The fabricated antenna has been measured using an Agilent E8362B network analyzer in its full operational span (10MHz–20GHz). Besides, measured and simulated results of reflection coefficient are exhibited in Figure 9. It is found that the proposed antenna not only has the capability of covering bandwidth of more than UWB band (from 2.85 to 17.8 GHz) for VSWR<2, but also it is able to filter interference bands of the 3.3-3.69, 5.15-5.825, and 8.025-8.4 GHZ for WLAN, WIMAX, ITU band applications. The great agreement between simulated and measured results is apparent and the little difference between them is attributed to factors such as SMA connector effects, implementation imperfections, and inappropriate quality of the microwave substrate. The y–z plane and the x–z plane are selected to show the antenna radiation patterns referred to as E-plane and H-plane, in order. Figure 10 shows the antenna normalized patterns at E-plane and H-plane. Regarding to it, we can conclude that the UWB antenna at E-plane has an almost bidirectional pattern and at H-plane also has a non directional pattern required to receive information signals from all directions.

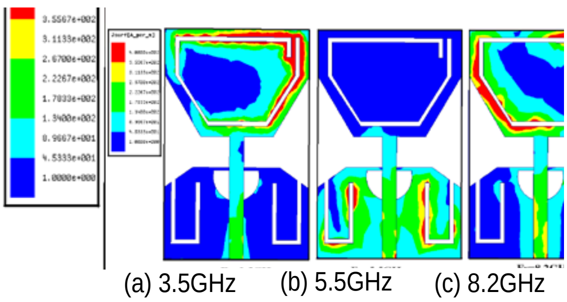

Fig. 8. Simulated current distribution on the patch at three frequencies

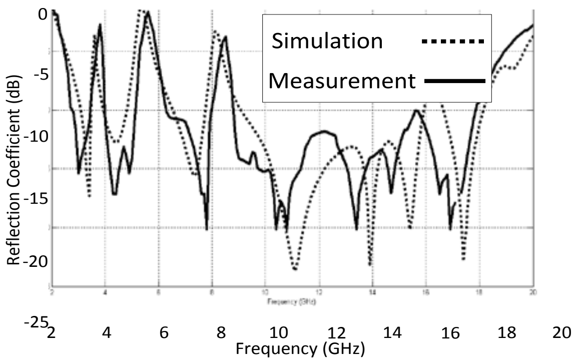

Fig. 9. Measured and simulated reflection coefficient of the proposed antenna with notch.

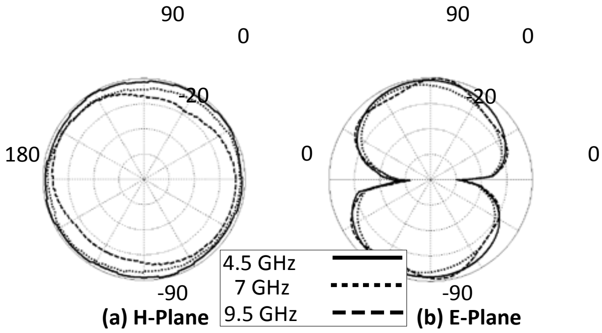

Fig. 10. Measured radiation patterns at three frequencies and two plane

CONCLUSIONS

In this paper, two new microstrip monopole antennas with very compact size for UWB application were presented, the former without notch and the latter with triple notches. By using a semi-circular slot in a new position, the bandwidth of this antenna has grown from 2.85GHz to 17.8GHz which it is more than defined UWB band. Also two-element arrays of such antennas in four different configurations for MIMO applications were analyzed. Simulated and experimental results show that the proposed antenna could be a good candidate for MIMO applications. Also measured Patterns of the antenna at three frequencies of 4.5, 7, and 9.5 GHz were presented.

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