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TRIPLE-BAND CPW-FED PLANAR MONOPOLE ANTENNA FOR WLAN/WiMAX APPLICATION

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Received 10 January 2013

A triple-band planar monopole antenna is presented in this article. The antenna consists of three strips which correspond to operating frequency bands of 2.4, 3.5, and 5.8 GHz. The proposed antenna has been designed, simulated, and fabricated on $20 \times 38 \text{ mm}^2$ FR4 board. There is good agreement between simulation and measurement results in terms of return loss and radiation pattern. The proposed antenna provides measured -10 dB bandwidths of 200 MHz for the 2.4 GHz (from 2.36 to 2.56 GHz); 620 MHz for the 3.5 GHz (from 3.48 to 4.10 GHz); and 1.38 GHz for 5.8 GHz (from 5.65 to 7.03 GHz). Moreover, the antenna provides the measured gain of 4.73, 1.66, and 3.28 dBi for 2.4, 3.5, and 5.8 GHz, respectively. The radiation characteristics have proven that the proposed antenna seems to be a good potential candidate for WLAN/WiMAX applications. © 2013 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 55:2209–2214, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27759

Key words: monopole antenna; triple-band antenna; WLAN; WiMAX

1. INTRODUCTION

Recently, there has been a lot of interest on multiband antennas for wireless communication, due to the increasing areas of application which require multiband frequency. Previous contributions of antenna designs for wireless communication have focused on planar monopole antenna due to its low cost, good

radiation pattern, and simplicity in fabrication [1–3]. Various studies of multiband antennas designed for WLAN and WiMAX applications have been reported in Refs. [4–7]. The antenna characteristics were investigated in those contributions, based on the radiating element shape, such as E-shape [5] and modified H-shape [7]. The antenna proposed for 2.4/5.2 GHz WLAN applications in Ref. [5] was investigated. The antenna size was $39 \times 30.5 \text{ mm}^2$, an E-shape radiating element was used; the bandwidth were 477 and 410 MHz for 2.4 and 5.2 GHz, respectively. The modified H-monopole antenna reported in Ref. [7] has dimensions of $32 \times 51.5 \text{ mm}^2$ and covers the 2.45/5.2 GHz WLAN and 3.5/5.5 GHz WiMAX. Moreover, a design using parasitic E-shaped as the radiating element was reported in Ref. [8], whereas the use of protruding stub in the ground plane was also proposed in Ref. [9]. Even though most of the reported designs reviewed in this study are suitable for WLAN/WiMAX applications, the antennas have serious drawbacks of complex structures and narrow bandwidth.

A planar coplanar waveguide (CPW) fed triple-band monopole antenna consisting of three patch strips for WLAN and WiMAX application is presented in this article. The three resonant frequencies are excited by these three patch strips. The simulation and parametric studies of the proposed antenna were done using the CST Microwave studio. The antenna has been fabricated and it covers the 2.4/5.8 GHz WLAN and 3.5 GHz WiMAX.

2. ANTENNA DESIGN

The antenna was fabricated on a FR4 substrate (thickness = 1.6 mm, relative permittivity = 4.4, and the loss tangent = 0.019); with dimensions of $20 \times 38 \text{ mm}^2$. The antenna comprises of three copper strips, in which each strip represents one resonant frequency. The antenna is fed by CPW which has a width $W_f = 2 \text{ mm}$ and the ground plane has a width W_g with the gap (g) between the feeding and ground planes. The antenna resonates at three different frequencies and the strip length determines the resonant frequency, which is approximately quarter wavelength of the operating frequency. For instance, the strip lengths are $(d_1 + d_2 + d_3 + d_4 + d_5)$, $(d_6 + d_7)$, and $(d_8 + d_9)$ for the 2.4, 3.5, and 5.8 GHz frequency bands, respectively. The geometry of the proposed CPW-fed tri-band monopole antenna is shown in Figure 1(a), whereas the antenna prototype is shown in Figure 1(b). The final optimized design parameters of the proposed antenna are as shown in Table 1.

The effects of three patch strips on the antenna performance are shown in Figures 2(a)–2(c). It can be observed from the simulated return loss as shown in Figure 3 that the antenna with strip length of $d_1 + d_2 + d_3 + d_4 + d_5$ provides the 2.4 and 5.8 GHz resonance frequencies. It can also be seen in Figure 2(b) that an additional strip length of $d_8 + d_9$ improves the bandwidth of the 5.8 GHz resonant frequency, whereas the 2.45 GHz resonant frequency remains unchanged. Figure 2(c) shows the proposed antenna with a strip length of $d_6 + d_7$, which provides the 3.5 GHz frequency band. The comparison of the simulated return losses for the proposed antenna design is shown in Figure 3.

3. RESULTS AND DISCUSSIONS

The return loss of the fabricated antenna has been measured using Agilent Technologies Vector Network analyzer E5071C. The measured and simulated return losses are presented in Figure 4, showing close agreement with some small deviation at 5.8 GHz. The return loss shows that the antenna has three

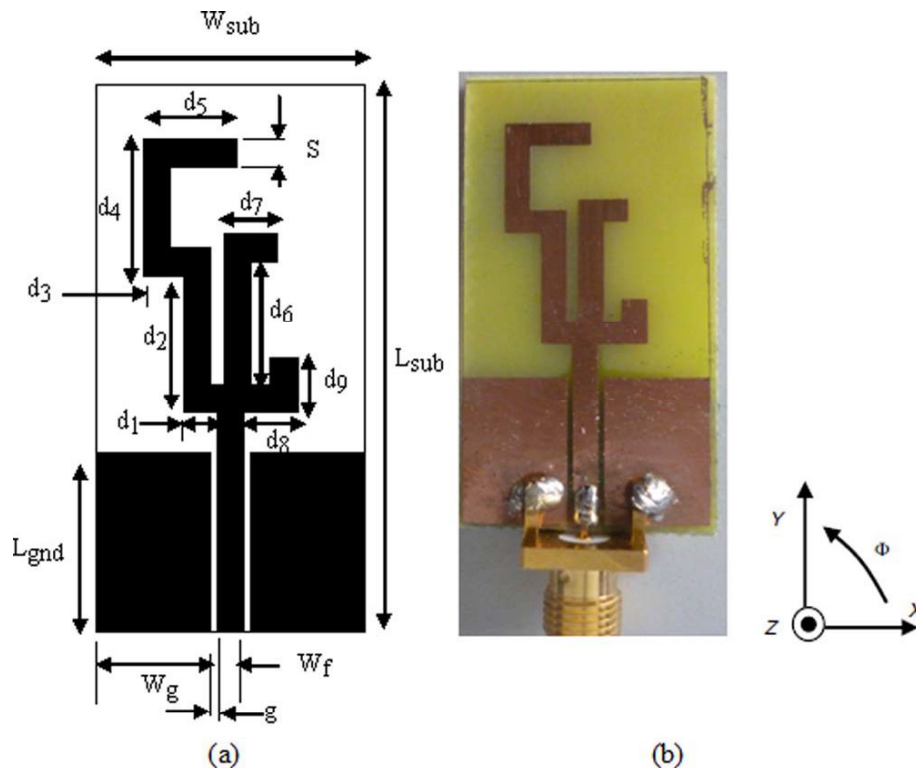


Figure 1 The geometry and prototype of the proposed triple band monopole antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

TABLE 1 Optimal Parameters of the Proposed Antenna (mm)

Notation	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_f	w_g	w_{sub}	L_{sub}	L_{gnd}	g
Value (mm)	2.5	10	3.0	10	5.0	9.0	4.0	4.0	2.0	3.0	16	8.5	20	40	13	0.5

resonant frequencies (2.4, 3.5, and 5.8 GHz) which cover the WLAN and WiMAX frequency bands.

The simulated -10 dB bandwidths are as follows: 300 MHz for the 2.4 GHz (from 2.28 to 2.58 GHz); 460 MHz for the 3.5 GHz (from 3.37 to 3.83 GHz); and 1.02 GHz for the 5.8 GHz (from 5.49 to 6.51 GHz). The corresponding values of measured -10 dB bandwidth are as follows: 200 MHz for the 2.4 GHz (from 2.36 to 2.56 GHz); 620 MHz for the 3.5 GHz (from 3.48 to 4.10 GHz); and 1.38 GHz for 5.8 GHz (from 5.65 to 7.03

GHz). Even though the measured and simulated have some deviation at 5.8 GHz frequency band, the measured -10 dB bandwidth can cover the WLAN and WiMAX frequency bands.

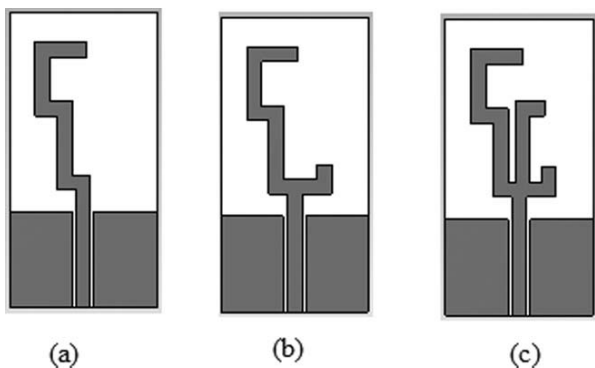


Figure 2 Design process of the proposed antenna (a) antenna 1, (b) antenna 2, and (c) proposed antenna

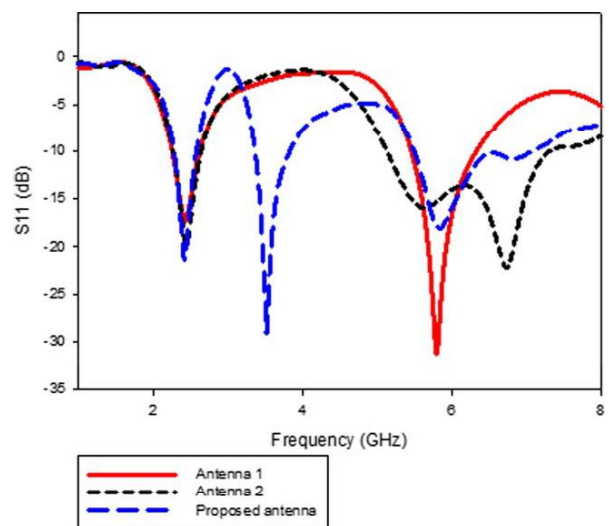


Figure 3 Comparison of return losses between the proposed antenna and antennas 1 and 2. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

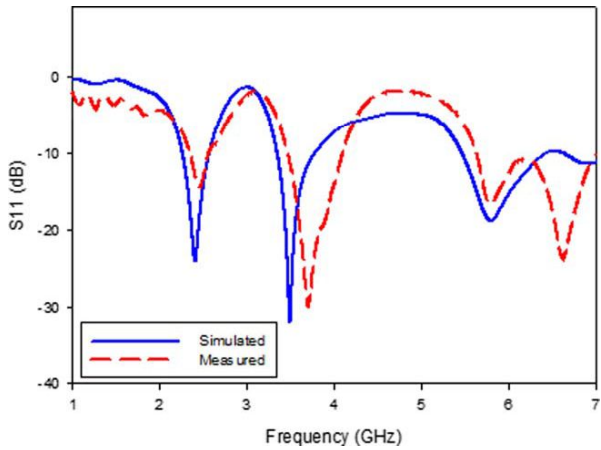


Figure 4 Measured and simulated return losses of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

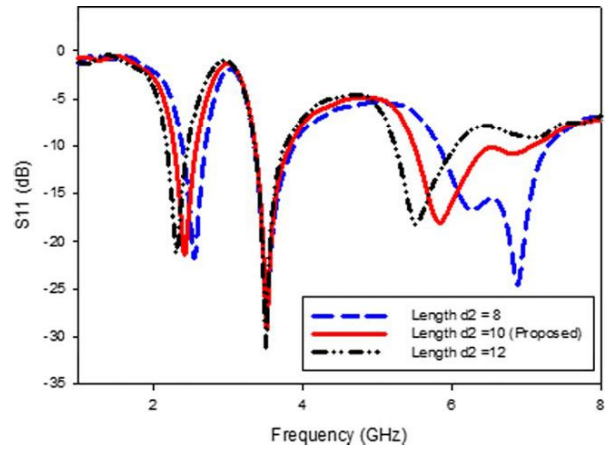


Figure 6 Comparison of simulated return loss for different values of length while other parameters remain constant. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

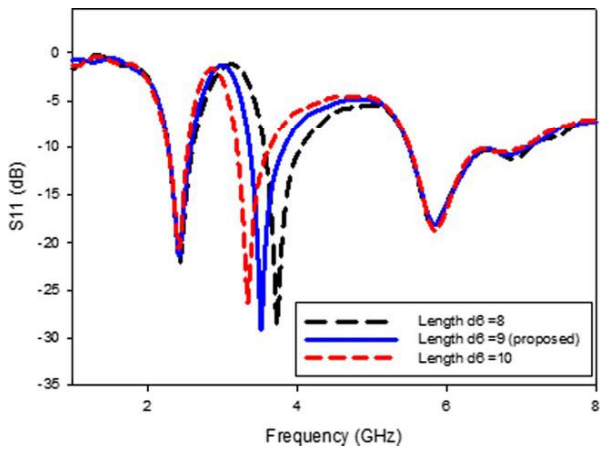


Figure 5 Comparison of simulated return loss for different values of length while other parameters remain constant. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

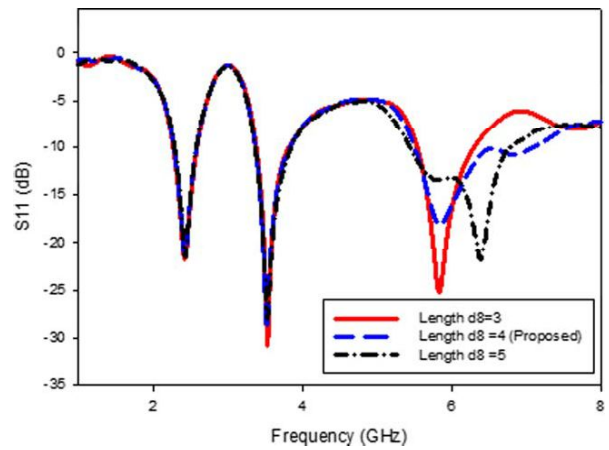


Figure 7 Comparison of simulated return loss for different values of length while other parameters remain constant. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

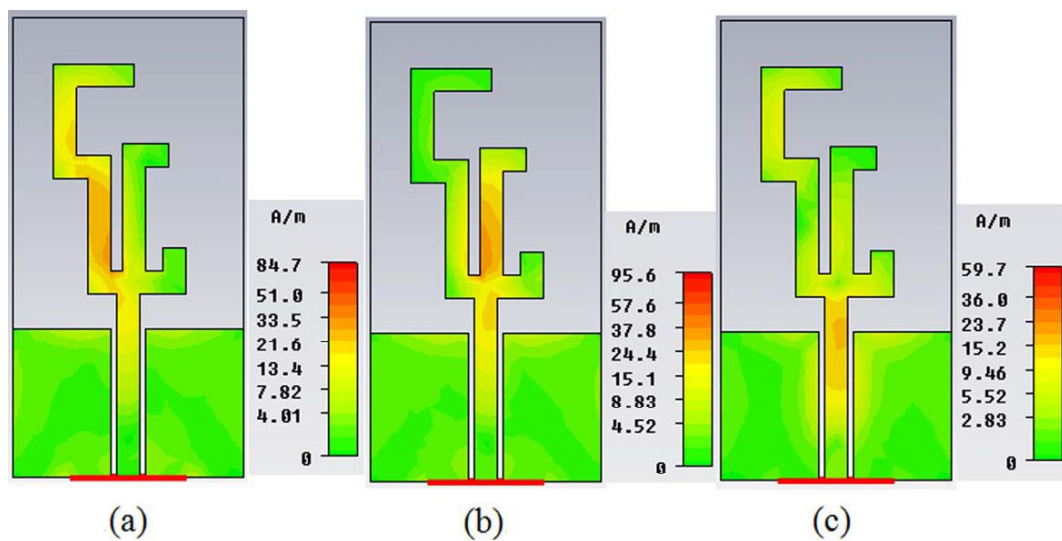


Figure 8 Simulated surface current distribution for the proposed antenna at (a) 2.4 GHz, (b) 3.5 GHz, and (c) 5.8 GHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

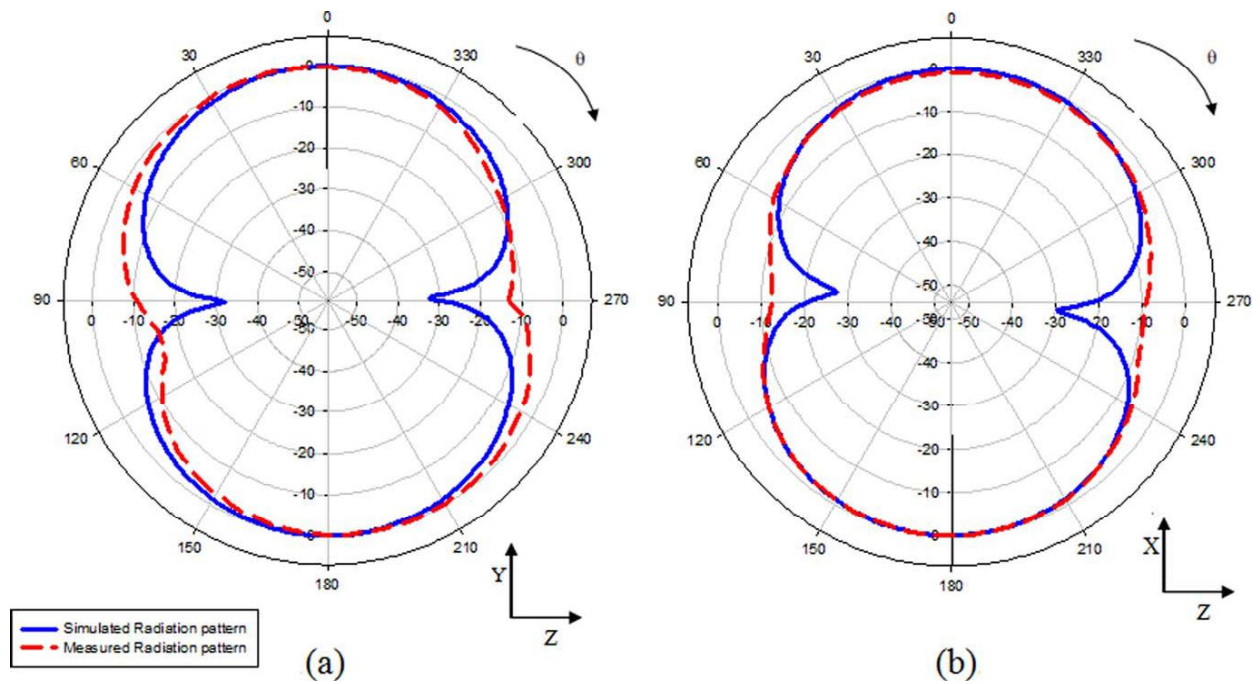


Figure 9 Measured and simulated radiation patterns of the proposed antenna at 2.4 GHz (a) E-plane and (b) H-plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

The parametric studies have been done to investigate the triple-band characteristics of the proposed antenna. The three parameters (L_3 , L_6 , and L_{10}) have been varied to demonstrate their effects on the antenna performance in terms of return loss. Note that each of the three parameters was varied at a time, while keeping the other two fixed. The effect of varying length d_6 on return loss is illustrated in Figures 5 and 6. The values of

d_6 have been varied from 6 to 10 mm. As can be observed from Figure 5, variation of d_6 has a significant effect on the 3.5 GHz resonant frequency, whereas other resonant frequencies remain unchanged. With decreasing the value of d_6 tends to shift the resonance frequency from the 3.5 GHz to a higher frequency, whereas increasing the value of d_6 causes the resonance frequency to shift to a lower frequency.

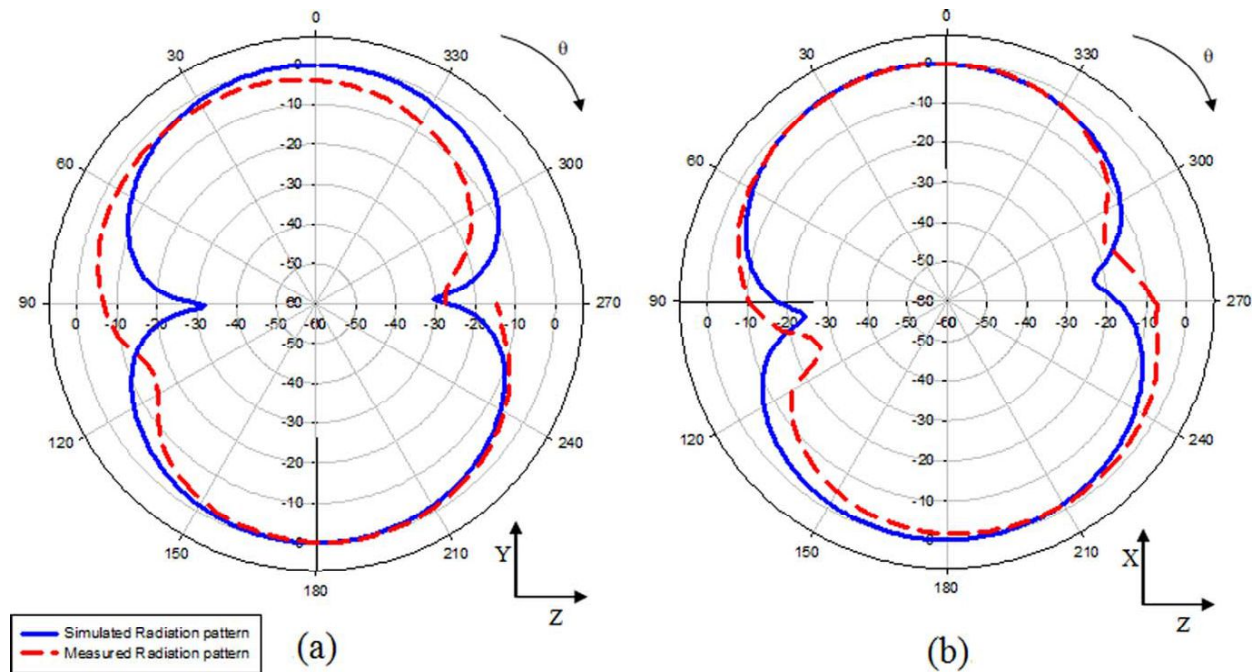


Figure 10 Measured and simulated radiation patterns of the proposed antenna at 3.5 GHz (a) E-plane and (b) H-plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

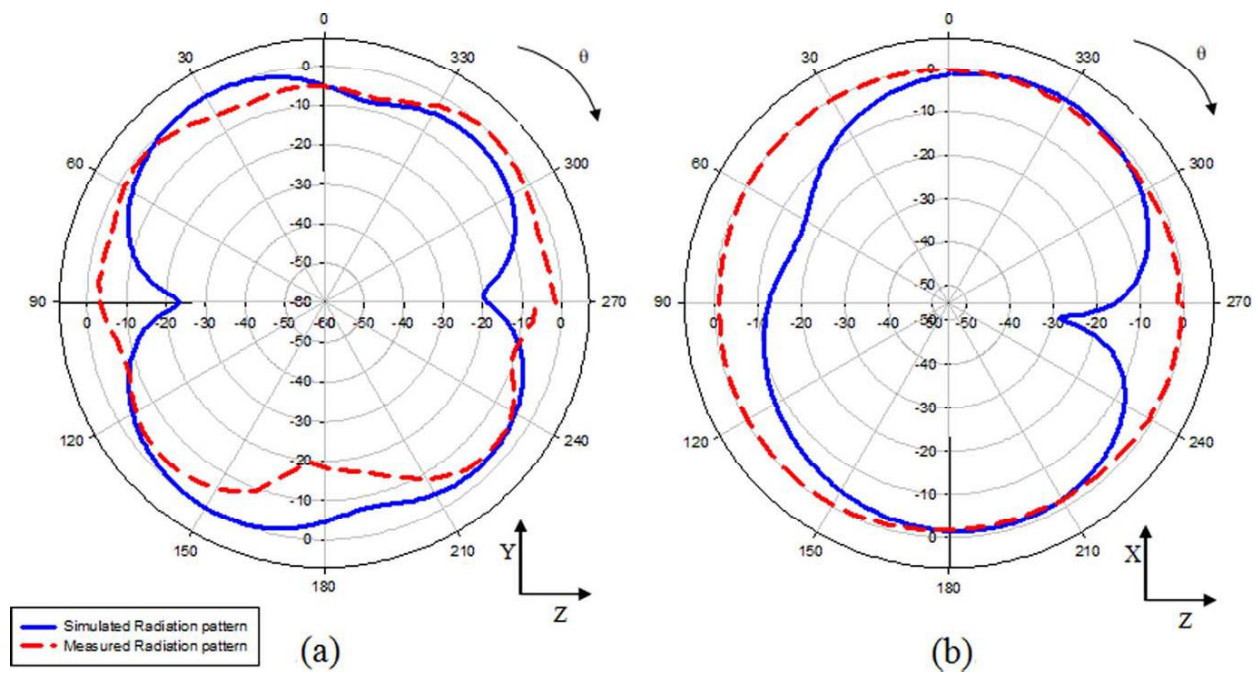


Figure 11 Measured and simulated radiation patterns of the proposed antenna at 5.8 GHz (a) E-plane and (b) H-plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Using CST Microwave studio for optimization, the optimal value of d_6 which yields the required 3.5 GHz resonant frequency is 9 mm (i.e., $d_6 = 9$ mm). The variations of return loss with different values of d_2 are shown in Figure 7. The value of d_2 has been varied from 8 to 12 mm. It can also be seen that d_2 has a significant effect on both 2.4 and 5.8 GHz resonant frequencies. The optimal value of $d_2 = 10$ mm has been used and it has given the best performance in terms of return loss. Moreover, the parameter d_8 has also been investigated as shown in Figure 8. The value of d_8 has been varied from 3 to 8 mm, and it was observed that d_8 only has effects on the 5.8 GHz resonant frequency. The two other resonant frequencies remain unchanged. Therefore, an optimal value $d_8 = 4$ mm was

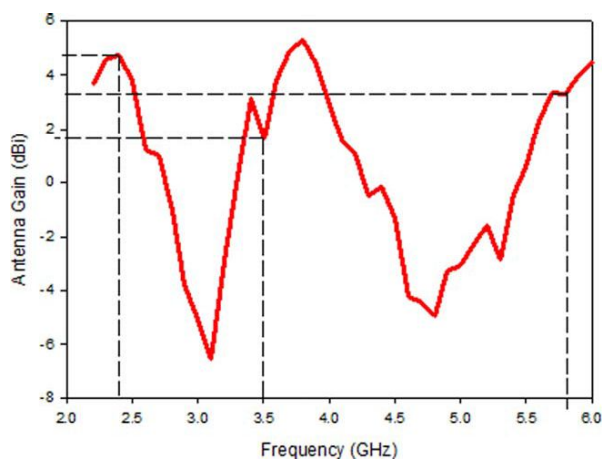


Figure 12 Measured gains of the triple-band planar monopole antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

used in the proposed antenna to obtain the optimal performance.

The current distributions of the proposed antenna are presented in Figures 8(a)–8(c), showing the current distribution for 2.45, 3.5, and 5.8 GHz frequency bands. It can be seen that the current is more concentrated on the $d_1 + d_2 + d_3 + d_4 + d_5$, $d_6 + d_7$, and $d_8 + d_9$ strips for the 2.45, 3.5, and 5.8 GHz resonant frequencies, respectively.

The measured and simulated radiation patterns of the proposed antenna have also been investigated. Figures 9–11 show the comparison of the measured and simulated radiation patterns (E-plane and H-plane) for 2.45, 3.5, and 5.8 GHz. The radiation pattern is close to omni-directional in the H-plane, as shown in these figures. The measured gain of the proposed antenna is shown in Figure 12. It can be seen that the gain at 2.4, 3.5, and 5.8 GHz are 4.73, 1.66, and 3.28 dBi, respectively. It has been observed from Figure 12 that there is gain reduction at 3.5 GHz compared to the other frequency band because the current is distributed in more than one frequency.

4. CONCLUSION

A triple band CPW-fed planar monopole antenna design has been investigated in this article. The proposed antenna was designed, fabricated, and tested, and there is close agreement between the measurement and simulation results. The proposed antenna provides measured -10 dB bandwidths of 200 MHz for the 2.4 GHz (from 2.36 to 2.56 GHz); 620 MHz for the 3.5 GHz (from 3.48 to 4.10 GHz); and 1.38 GHz for 5.8 GHz (from 5.65 to 7.03 GHz). Besides, it also provides the measured gain of 4.73, 1.66, and 3.28 dBi for 2.4, 3.5, and 5.8 GHz, respectively. The antenna radiation pattern is close to omni-directional. Therefore, the proposed antenna is a suitable candidate for WLAN and WiMAX applications.

ACKNOWLEDGMENTS

The authors would like to thank to Ministry of Higher Education (MOHE) and UTM GUP (vote 01H00 and vote 00G36) for sponsoring this work. Besides, thanks to the members of Wireless Communication Center (WCC), UTM for helping and providing resources to enable this work to be completed. Finally, a special thanks goes to University of Dar es Salaam (UDSM) for the scholarship.

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COMPACT UWB MULTILAYER 3 dB DIRECTIONAL COUPLER DESIGN AND ANALYSIS ON COUPLER PERFORMANCES

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Received 10 January 2013

ABSTRACT: An extended works of a diamond shaped 3 dB coupler design that is operating in ultra-wideband frequency range is presented in this article. The proposed design is accomplished by using multilayer technology in which the structure is formed by three layers of conductors and interleaved by a layer of substrate between each one of the conductor layer. The proposed designed coupler simulation result

shows that the design exhibits a coupling of 3 dB return loss and isolation better than 22 and 21 dB, respectively. Whereas, the phase difference performance is in the range of $90^\circ \pm 2^\circ$ over the designated band. The coupler is fabricated and measured. Analysis studies on the parametric value are presented and discussed to observe the effect of the dimension of the patch to the performance of the coupler. © 2013 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 55:2214–2219, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27773

Key words: microstrip-slot; multilayer; ultra-wideband; coupler design; Butler matrix

1. INTRODUCTION

Since the news of the ultra-wideband frequency that cover between 3.1 and 10.6 GHz that has been allocated by Federal Communication Commission spreads in February 2002 [1–7], a lot of application for the communication and radar system [8–12] is being investigated. This has influenced the excessive increment of the design approach for the directional couplers design [13–17]. Where, directional couplers are among the most well-known passive devices that have widely been used in microwave subsystems, such as in beam-forming network, modulators, and balanced mixers [18]. As widely use passive component these days, most of the researchers found out that it is a need to design the directional coupler that can operate in ultra-wideband frequency.

However, it is very difficult to design a directional coupler with a very tight coupling over a very wide frequency band. One of the most popular methods in solving this problem is by using coupled transmission line which was reported by Lange [19]. However, to achieve tight coupling with reasonable strip of widths and gaps, Lange's coupler needs a very high-dielectric constant substrate. Lower dielectric constant substrate leads to narrower strip widths and gaps, which will create problems during the manufacturing process.

Slot-coupled directional coupler is another technique to achieve tight coupling but the bandwidth that can operate for this coupler design is limited. Due to this, the use of multilayer technology in coupler design has been introduced by Tanaka et al. [20]. Where, this technique is proven can enhance the bandwidth performance. Different from Tanaka's approach, de Ronde's [21] has proposed a very compact coupler design and the coupler shows that it was able to operate almost 4:1 frequency range. However, the use of the capacitive disc below the slot line creates a complexity of the circuit design. Later, Garcia [22] proposed a modification to the de Ronde's design where by widening the slot size below the microstrip layer, the bandwidth of the coupler can also be enhanced with simpler circuit design.

Few years later, few types of coupler design [23–25] have been proposed to offer broadband frequency coverage but unfortunately none of them manage to cover the whole ultra-wideband frequency from 3.1 to 10.6 GHz. Table 1 shows the summarization of the coupler mentioned previously in terms of the bandwidth.

In this article, an extended works from the authors' previous work in Ref. [26] regarding a design of diamond-shaped coupler which able to provide 3 dB coupling over the whole ultra-wideband frequency range is proposed. To examine the performance of the designed coupler for the real environment, the design is fabricated and measured. The multilayer microstrip techniques compromise very large bandwidth so that the coupler can be used in ultra-wideband frequency range. The designed coupler is one of the alternative methods to develop a tight coupling and