ON-FRAME DUAL-LOOP ANTENNA WITH NARROW GROUND CLEARANCE FOR THE 2.4/5.2/5.8-GHz WLAN OPERATION IN THE SMARTPHONE

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ABSTRACT: *A dual-loop antenna with a 1-mm ground clearance on the main circuit board and an on-frame metal patch for the 2.4/5.2/5.8-GHz multiband WLAN operation in the smartphone was presented. The metal patch was printed on the inner surface of the side-edge frame of the smartphone and has a simple rectangular shape of size 6 × 12.7 mm^2. Multiband operation of the antenna was obtained by short-circuiting the metal patch at two positions, respectively, through a capacitive shorting strip and a simple shorting strip, to the system ground plane on the main circuit board. In this case, two loop paths of different resonant lengths with acceptable isolation were obtained for the antenna to generate two wide operating bands. The larger (outer) and smaller (inner) loops thereof could generate their fundamental loop modes with corresponding resonant lengths much less than 0.25 wavelength (only about 0.12 wavelength at 2.45 GHz for the outer loop and about 0.17 wavelength at 5.5 GHz for the inner loop). The greatly decreased resonant lengths were owing to the aid of a simple matching circuit (a series capacitor and a series inductor) disposed on the main circuit board. The generated loop modes could cover the 2.4-GHz (2400–2484 MHz) and 5.2/5.8-GHz (5150–5350/5725–5875 MHz) WLAN bands. With narrow ground clearance and small on-frame metal patch, the dual-loop antenna was especially suitable to fit in the narrow region between the display panel and the side edge of the smartphone casing. Details of the proposed antenna and its working principle were presented.* Microwave Opt Technol Lett 58:1480–1485, 2016; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.29825

Key words: *mobile antennas; smartphone antennas; loop antennas; WLAN antennas; on-frame antennas; antennas with narrow ground clearance*

1. INTRODUCTION

Traditionally, the internal antennas for the smartphone are embedded in close proximity to the top or bottom edges of the main circuit board therein. It is also noted that, owing to the recent multiinput multioutput (MIMO) operation requirement for the long-term evolution (LTE) system [1–4] or the wireless local area network (WLAN) system [5–10] to increase the channel capacities [11,12], more internal antennas are needed to be embedded within the very limited space in the smartphone. For example, two LTE antennas for the 2 × 2 LTE MIMO and/or two WLAN antennas for the 2 × 2 WLAN MIMO operation have been deployed in some tablet devices. The design with more antennas embedded in the tablet device for the 4 × 4 LTE and WLAN MIMO operations are also being devised in order to achieve a much higher channel capacity. With the increasing number of the internal antennas required, the antenna design for the tablet device such as the smartphone is becoming more critical than ever. This motivates the present study to explore the narrow regions along the two side edges of the main circuit board to accommodate the internal antennas.

Note that the narrow width along the two side edges of the smartphone is owing to the large display panel used for the smartphone. To fit in such narrow regions, the internal antenna should be with narrow ground clearance. For example, the ground clearance may be required to be only 1 mm or so. For this application, a small-size on-frame dual-loop antenna for the 2.4/5.2/5.8-GHz WLAN operation in the smartphone is presented. The antenna presented in this study requires a 1-mm ground clearance only. The antenna also has a simple metal patch, which can be printed on the inner surface of the side-edge frame of the smartphone casing. In order to provide two wide bands for the 2.4/5.2/5.8-GHz WLAN operation, a technique of short-circuiting the on-frame metal patch at two positions to the system ground plane on the main circuit board to create two loop paths of different resonant lengths is proposed. One short-circuiting is through a simple shorting strip and another one is through a chip capacitor (denoted as a capacitive shorting strip in this study). The two created loops can have acceptable isolation for the dual-band operation.

In addition, with the aid of an on-board simple matching circuit (a series chip capacitor and a series chip inductor), the two loops can contribute their fundamental modes with resonant lengths much less than 0.25 wavelength. This property leads to a small size for the antenna to cover the 2.4-GHz (2400–2484 MHz) and 5.2/5.8-GHz (5150–5350/5725–5875 MHz) WLAN operation. Details of the proposed antenna are described in this article. The techniques of achieving the two loop resonant paths with acceptable isolation using two hybrid short-circuiting connections and generating the two loop resonant modes with decreased resonant lengths using the on-board matching circuit are addressed. The antenna is also fabricated and tested to verify the simulated results.

2. ANTENNA STRUCTURE AND OPERATING PRINCIPLE

2.1. Antenna Structure

Figure 1 shows the geometry of the on-frame dual-loop antenna with a narrow ground clearance for the 2.4/5.2/5.8-GHz WLAN operation in the smartphone. As shown in the figure, the smartphone has a 6-inch display panel on the system ground plane of the main circuit board (size 75 × 150 mm^2). In this study, a 0.8-mm thick FR4 substrate of relative permittivity 4.4 and loss tangent 0.02 is used to simulate the main circuit board, and note that the display panel is not included in the study for simplicity. The antenna comprises a simple rectangular metal patch (section AB) of length 12.7 mm and width (w) 6 mm printed on the inner surface of the side-edge frame of the smartphone. A 0.8-mm thick FR4 substrate of width 6 mm and length 150 mm is also used to simulate the side-edge frame. Note that, in the study, it is assumed that the smartphone has a thin thickness of 6 mm only, so that the width of the side-edge frame thereof is selected to be 6 mm. Also, to simplify the simulation and experimental studies, the dielectric frame along the other three edges is not added, which is expected to have negligible effects on the obtained results here.

The on-frame metal plate is disposed away from the corner of the top edge with a distance (d) of 15 mm. The distance d can be varied for practical applications, and its effects will be analyzed in Section later. To create two loop resonant paths for the multiband operation, the metal plate is shorted at point B and D, respectively, through a simple shorting strip of width 1.5 mm (section BB') and a chip capacitor C_2 (0.6 pF) to the system ground plane printed on the back surface of the main circuit board. In this case, a dual-loop antenna is obtained, and its equivalent structure is shown in Figure 2. The photos of the fabricated antenna are also shown in Figure 3 for easy

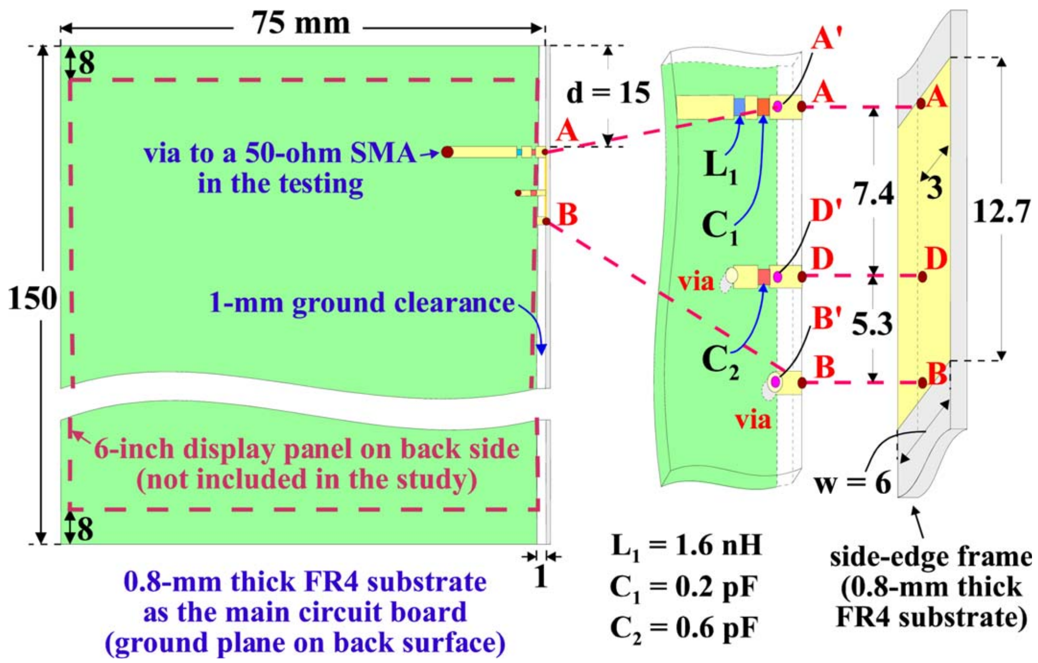

Figure 1 Geometry of the on-frame dual-loop antenna with a narrow ground clearance for the 2.4/5.2/5.8-GHz WLAN operation in the smartphone. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

understanding of the antenna structure. The outer loop (path A'ABB') has a path length of 14.7 mm, which corresponds to be only about 0.12 wavelength at 2.45 GHz, whereas the inner loop (path A'ADD') has a path length of 9.4 mm, which is only about 0.17 wavelength at 5.5 GHz. The two path lengths are much smaller than the generally required 0.25 wavelength (e.g., the inverted-F antenna [13,14]) at their resonant frequencies and can support two loop modes to cover the 2.4-GHz and 5.2/5.8-GHz WLAN operation. This feature leads to a smaller antenna size required for the desired WLAN operation. The smaller loop resonant lengths are owing to the aid of the on-board matching circuit consisting of a series chip capacitor C_1 (0.2 pF) and a series chip inductor L_2 (1.6 nH) connected to the antenna at point A'. Its working principle is discussed in the next section.

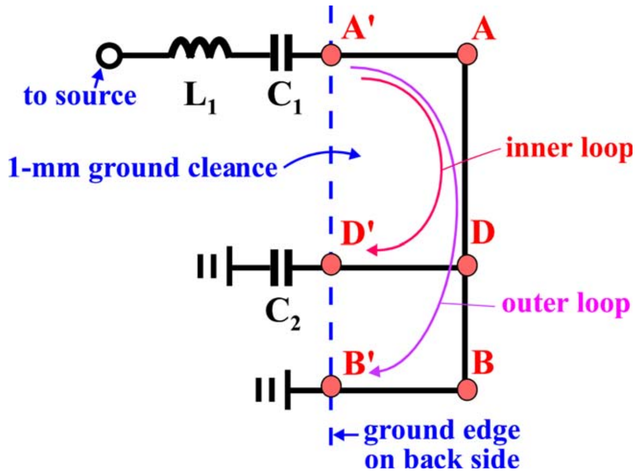

Figure 2 Equivalent structure of the dual-loop antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

2.2. Working Principle

To analyze the working principle, Figure 4 shows the simulated return loss for the proposed antenna, the inner loop antenna only (Ant1), and the outer loop antenna only (Ant2). The simulated results are obtained using the simulation software high frequency structure simulator (HFSS) version 15 [15]. The shaded

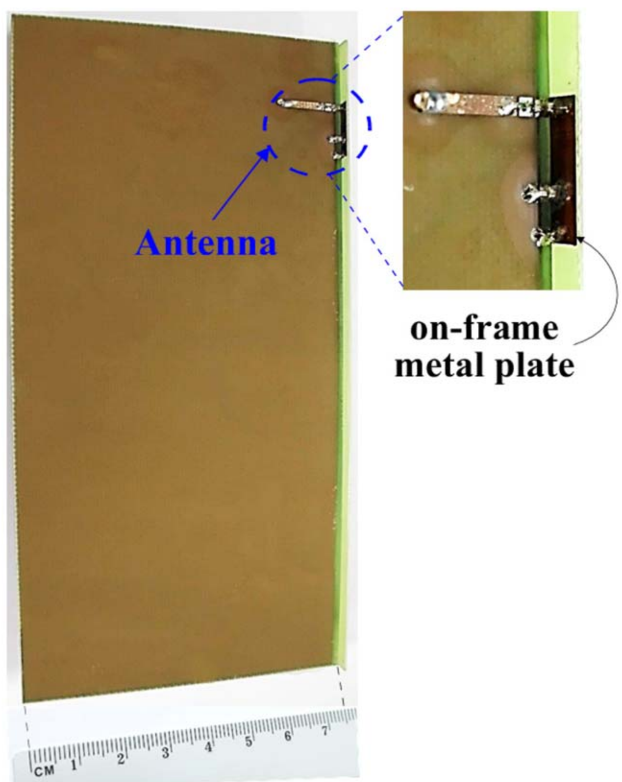

Figure 3 Photos of the fabricated antennas. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

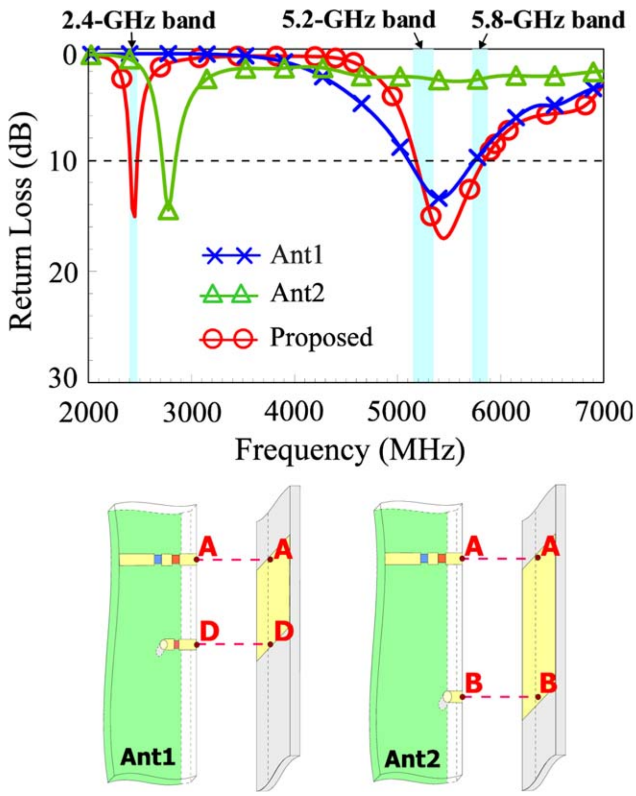

Figure 4 Simulated return loss for the proposed antenna, the inner loop antenna only (Ant1), and the outer loop antenna only (Ant2). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

frequency regions in the figure represent, respectively, the 2.4-GHz WLAN band (2400–2484 MHz), the 5.2-GHz WLAN band (5150–5350 MHz), and the 5.8-GHz WLAN band (5725–5875 MHz). Corresponding dimensions of the three antennas in the figure and the matching circuit used therein are the same. It is first noted that the proposed antenna generates a lower and a higher operating bands to respectively cover the 2.4-GHz and 5.2/5.8-GHz WLAN operation. For Ant1, it contributes a resonant mode at about 5.5 GHz to cover the 5.2/5.8-GHz bands. On the other hand, Ant2 generates a resonant mode at frequencies close to the 2.4-GHz band. The results suggest that the lower and the higher bands of the antenna are contributed by Ant2 and Ant1, respectively. That is, the inner and the outer loop resonant paths of the antenna account for the two resonant modes generated for the desired 2.4/5.2/5.8-GHz WLAN operation.

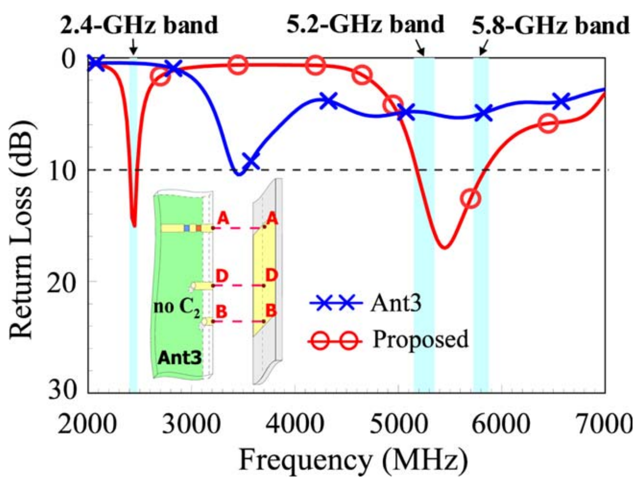

Figure 5 Simulated return loss for the proposed antenna and the case with the capacitor C2 replaced by a shorting strip in the inner loop path (Ant3). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

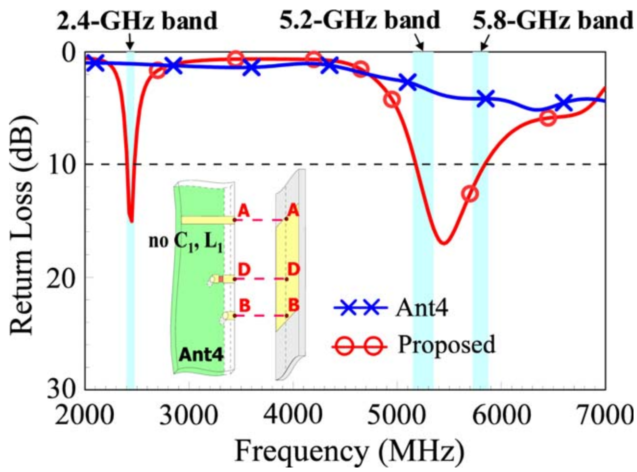

Figure 6 Simulated return loss for the proposed antenna and the case without the on-board matching circuit of a series capacitor C1 and a series inductor L1 (Ant4). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

In addition, it is seen that the added capacitive shorting connection (the section DD' with the series capacitor C_2 short-circuited to the system ground plane) [16] not only creates an additional loop resonant path for the 5.2/5.8-GHz bands, but also shifts the resonant mode contributed by the outer loop resonant path to lower frequencies. This can explain that the outer loop resonant path has a much lower resonant length (about 0.12 wavelength at 2.45 GHz) than the inner loop resonant path (about 0.16 wavelength at 5.5 GHz).

Effects of replacing the capacitive shorting strip by s simple shorting strip are also studied. Results of the simulated return loss are shown in Figure 5. Ant3 in the inset of the figure shows the case with the capacitor C_2 replaced by a simple metal strip. Results clearly show that the resonant mode occurred at about 5.5 GHz for the proposed antenna cannot be generated for Ant3. The resonant mode contributed by the outer loop resonant path is also shifted to higher frequencies larger than 3 GHz. Note that the resonant mode contributed by Ant2 occurs at frequencies lower than 3 GHz (see the results in Figure 4). The added capacitive shorting connection is hence important in the proposed antenna to generate two resonant modes for the desired multiband WLAN operation.

Effects of the on-board matching circuit (C_1 and L_1) are studied with the aid of Figure 6. Results of the simulated return loss for the proposed antenna and the case without the on-board matching circuit (Ant4) are presented. It is interesting to see that the two loop resonant modes disappear for Ant4. This indicates that the generation of the loop resonant modes for both the two loop resonant paths (the outer and inner ones) is mainly owing to the added on-board matching circuit. This behavior is related to the quarter-wavelength loop antenna reported in [17–19], in which, however, only one single quarter-wavelength loop resonant mode is generated. In the present design, results show that two quarter-wavelength loop resonant modes can be

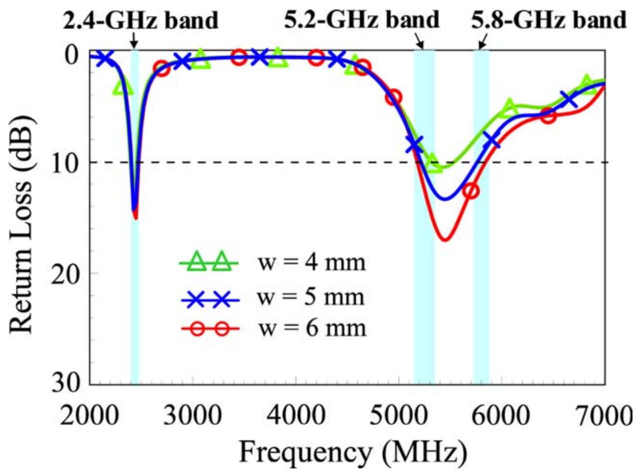

Figure 7 Simulated return loss of the antenna as a function of the width, *w,* of the on-frame metal patch. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

obtained to achieve dual-band operation for the 2.4/5.2/5.8-GHz WLAN operation with a simple, small-size antenna structure.

3. PARAMETRIC STUDY

Effects of the width *w* of the on-frame metal patch on the antenna performance are analyzed with the aid of Figure 7. Results of the simulated return loss for the width *w* varied from 4 to 6 mm are presented. Other parameters of the antenna are the same as given in Figure 1. It is seen that the impedance matching for the 2.4-GHz band is very slightly affected. On the other hand, the decrease in the width *w* causes the impedance matching degradation for the 5.2/5.8-GHz bands. The on-frame metal patch with a larger width is hence used in this study to achieve good impedance matching for the desired 2.4/5.2/5.8GHz WLAN operation.

Figure 8 shows the simulated return loss of the antenna as a function of the distance *d* away from the corner of the short edge. The antenna parameters are the same as shown in Figure 1. The case with a larger distance *d* indicates that the antenna is moved closer to the center of the side edge. Results show that

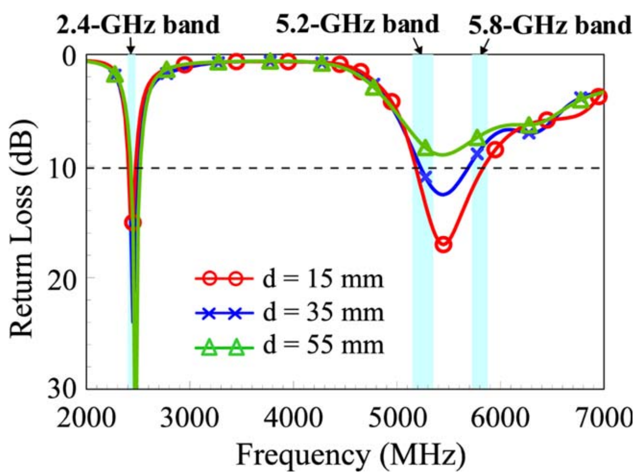

Figure 8 Simulated return loss of the antenna as a function of the distance, *d*, away from the corner of the short edge. The antenna parameters are the same as shown in Figure 1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

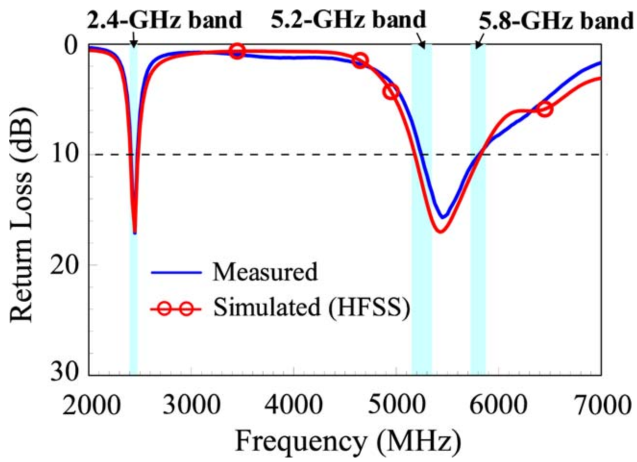

Figure 9 Measured and simulated return losses for the fabricated prototype. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

there are relatively large effects on the impedance matching of the resonant mode in the higher band. On the other hand, small effects are observed for the resonant mode in the lower band. This behavior could be attributed to the use of the capacitive shorting strip to connect the inner loop to the system ground plane. When the antenna is moved along the side edge, the capacitive shorting connection could be more sensitive to the position variation than the simple shorting connection that connects the outer loop to the system ground plane. Hence, the resonant mode in the higher band that is contributed by the inner loop will be more sensitive to the position variation as shown in Figure 8. From the results, in order to obtain better impedance matching for both the lower and higher bands, the antenna is selected to be close to the corner of the side edge with a distance of 15 mm.

4. EXPERIMENTAL RESULTS

The proposed antenna is fabricated as shown in Figure 2. The measured and simulated return losses for the fabricated prototype are shown in Figure 9. The measured data are in good agreement with the simulated results. The measured return loss generally covers the 2.4-GHz and 5.2/5.8-GHz WLAN bands.

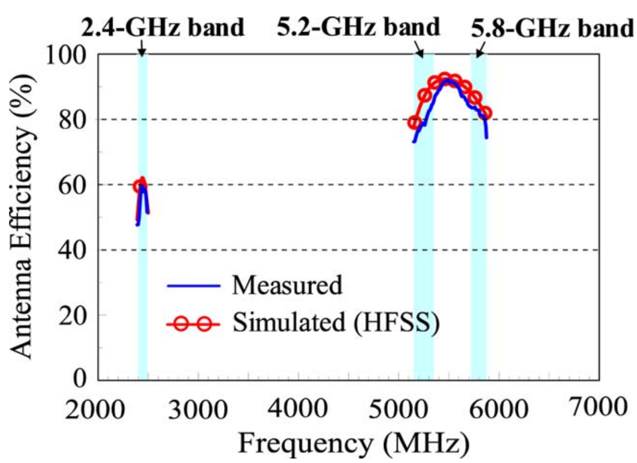

Figure 10 Measured and simulated antenna efficiencies for the fabricated prototype. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

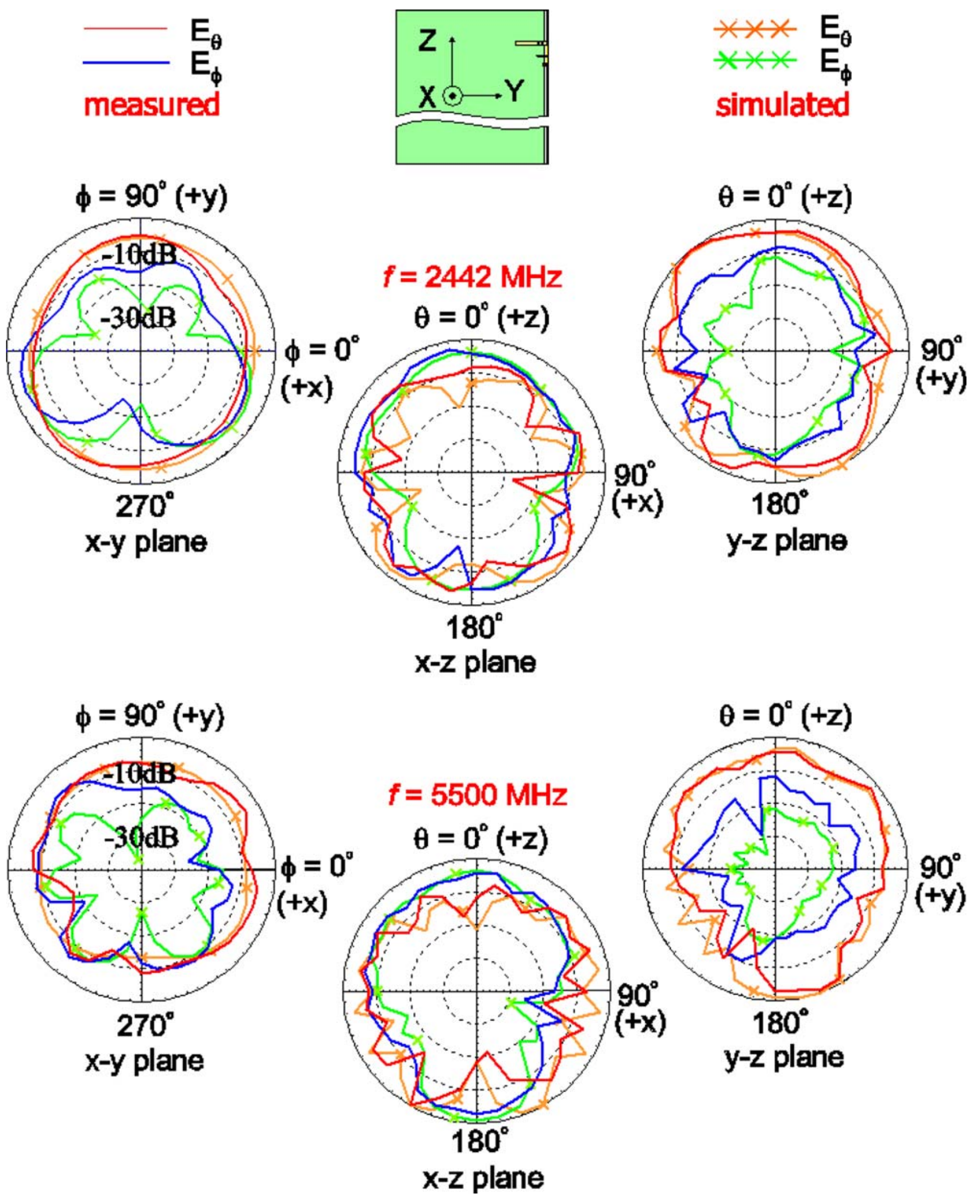

Figure 11 Measured and simulated radiation patterns for the fabricated prototype. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Note that the impedance matching of the edge frequencies in the higher band is slightly less than 10 dB. The measured antenna efficiencies which include the mismatching losses, however, are better than about 75% in the 5.2- and 5.8-GHz bands (see the results in Fig. 10). The obtained antenna efficiencies are good for practical applications. In the 2.4-GHz band, the measured antenna efficiencies are better than 48%, which is also acceptable for practical applications. In Figure 10, it is also seen that the measured antenna efficiencies agree with the simulated results.

Figure 11 shows the measured and simulated radiation patterns for the fabricated prototype. Results at two representative frequencies at 2442 and 5500 MHz (center frequencies of the 2.4- and 5.2/5.8-GHz bands) are plotted. The radiation patterns are measured in a far-field anechoic chamber. The measured radiation patterns also in general agree with the simulated results. For the obtained radiation patterns at the two frequencies, there are generally no nulls in the E_θ radiation in the azimuthal plane (*x–y* plane). This is advantageous in practical applications to have better coverage in all the azimuthal directions. The radiation patterns in the two elevation planes (*x–z* and *y–z* planes) also show no special distinctions as compared with those of many reported WLAN antennas [13]. That is, the radiation patterns of the proposed antenna will be acceptable for practical WLAN applications.

5. CONCLUSION

An on-frame dual-loop antenna for the 2.4/5.2/5.8-GHz WLAN operation has been proposed for the smartphone application. The antenna requires a narrow ground clearance of width 1 mm on the main circuit board of the smartphone, making it suitable to be disposed along the narrow region between the large display panel and the side edge of the smartphone casing. The antenna also has a simple structure formed by an on-board matching circuit and an on-frame rectangular metal patch. The latter is short-circuited to the system ground plane on the main circuit board through two hybrid shorting connections (a capacitive and a simple shorting connections), thereby creating two resonant loop paths of different lengths to generate a loop mode at lower frequencies for the 2.4-GHz WLAN operation and a loop mode at higher frequencies for the 5.2/5.8-GHz WLAN operation. The two loop modes are easily controlled by the on-board matching circuit to have a resonant length much smaller than a quarter-wavelength, which leads to a small size of 6×12.7 mm^2 required for the proposed antenna for the 2.4/5.2/5.8-GHz WLAN operation. Good radiation characteristics of the proposed antenna have also been obtained. The antenna should be promising for application as a side-edge antenna for the WLAN operation in the smartphone.

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AN E-SHAPED MICROSTRIP PATCH ANTENNA FOR RECONFIGURABLE DUAL-BAND OPERATION

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ABSTRACT: *A simultaneous dual-band frequency reconfigurable E-shaped microstrip patch antenna is proposed in this paper. The antenna is capable of efficiently switching both the frequency bands at the same time without the need of any external matching network. Its structure is simple and consists of a single-layer inset-feed patch and three RF switches placed at appropriate locations to reconfigure the frequency bands. The proposed antenna resonates at 3.5 GHz and 8.1 GHz when the PIN diodes are 'OFF' (reverse biased) but reconfigured to 3.1 GHz and 7.2 GHz when the PIN diodes are turned 'ON' (forward biased). A full wave simulation tool HFSS v. 15.0 is used for the analysis of the proposed E-shaped microstrip patch. Moreover, an edge-fed technique is introduced to simplify the design and simple biasing circuit has been incorporated in the fabricated design. A gain of 4.6 dBi, 5.2 dBi, 4.0 dBi, and 4.4 dBi is measured at 3.1 GHz, 3.5 GHz, 7.2 GHz, and 8.1 GHz, respectively. Good agreement is achieved between simulated and measured results. Its ability to resonate at multiple frequencies in the S-, C- and X-bands makes this antenna suitable for WIMAX applications, microwave communications and satellite links.* © 2016 Wiley Periodicals, Inc. Microwave Opt Technol Lett 58:1485–1490, 2016; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.29814

Key words: *E-shaped microstrip patch antenna; frequency reconfigurable antenna; dual band antenna*

1. INTRODUCTION

The ever increasing demand of wireless communication systems has attracted significant interest in antenna research. Many novel designs are being proposed to cover various bands of frequencies, with some covering multi-bands and ultra-wide bands [1]. Multi-bands can be covered with the help of a frequency reconfigurable antenna, motivating designers to use different structures to achieve the re-configurability and sometimes designing complex 3D structures, as in Ref. [2]. Designing a dual-band antenna is possible with certain approaches to control the current distribution of one of the higher order resonant modes of the structure, enabling it to change its resonant frequency [3]. Hu et al. [4] proposed a dual band reconfigurable antenna but used two external matching circuits. A wideband E-shaped microstrip patch antenna had also been proposed in the Refs. [5] and [6] but a complex structure containing air between the ground plane and radiating patch is used. A little deflection of either the ground or radiating patch can alter the radiating frequencies. Recently a linearly polarized E-shaped patch antenna with wide-band applications had been proposed for its design simplicity and single layer wide bandwidth characteristics [7]. However, most of these E-shaped patch antennas have been designed using a coaxial feed [8], which can introduce an inductance into the feed and also the probe will radiate which