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Study of user effects on two-port MIMO antennas at 2.4 GHz and 5.8 GHz for Wi-Fi and WLAN applications

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ABSTRACT

In this paper, two multiple input multiple output (MIMO) antennas for Wi-Fi/WLAN mobile applications are proposed. The designed two-port MIMO antennas are made up of planar inverted-F antennas (PIFAs). The antenna elements for both designs are symmetrical and placed on the short-edged corners of the substrate used, FR4. The performance of both antennas in the presence of user's hand is compared in terms of impedance bandwidth and efficiency. An upward shift of up to 0.17 GHz in impedance bandwidth was found for 2.4 GHz and 5.8 GHz antenna. Due to the smaller size of antennas at 5.8 GHz compared to antennas at 2.4 GHz, the antennas are less obstructed by hands and thus the exhibited total efficiency of up to 45.58 % in the presence of human hand. The designed antennas have been fabricated for validation purpose. It is shown that there is a good agreement between simulated and measured results.

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343

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1. INTRODUCTION

Multiple-input-multiple-output (MIMO) technology has become an important technique in communication system. Nowadays, MIMO antennas with extensive cellular coverage and satisfactory isolation and radiation performance are concentrated area of research [1]. It is an immense challenge to ensure that the antennas in mobile terminal meet the vital criteria. The antennas should be in compact sizes and able to conform to diverse standards and requirements [2-4]. As these antennas are located in mobile terminals, various studies have been done previously that showed the performance of the antenna in mobile terminal are significantly affected by the presence of users, especially when the mobile antenna is being held by the users, close to their heads [5-13].

In this paper, two simple MIMO planar inverted-F antennas (PIFAs) for Wi-Fi and WLAN applications are presented. The antenna elements are symmetrically-positioned on the corners of the short edge of the ground plane. The operating frequencies are 2.4 GHz and 5.8 GHz, respectively. Finally the performance analysis of both antennas has been evaluated in the presence of user's hand. The simulation designs of the antennas are measured with hand phantom to show the user's effect on the MIMO antennas.

2. ANTENNA DESIGNS

The simulated models of the two-port MIMO antennas are shown in Figure 1 and Figure 2. The substrates used for both MIMO antennas are FR-4 boards with the same dimension of 55 (W) x 110 (L) x 1.6 (H) $\,$ mm 3 . The antennas are simple PIFAs, designed to operate at 2.4 GHz and 5.8 GHz for Wi-Fi and WLAN

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344 🗖 ISSN: 2302-9285

applications. The PIFAs are positioned on the short-edged corners of the FR4, whereas the antenna elements are symmetrically designed. The resonant frequency of a PIFA is not solely decided by the patch's length but it is proportional to the summation of its length and width, which is roughly a quarter wavelength of its resonant frequency [14].

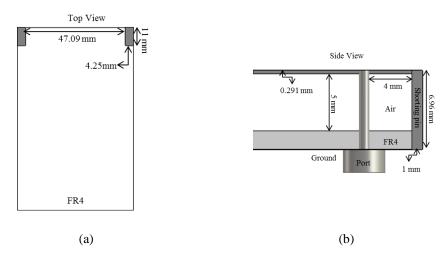


Figure 1. The design view of 2.4 GHz MIMO antenna showing (a) top view and (b) side view

The antenna elements are placed at the edge of the substrate because it is known that it improves the impedance, bandwidth and radiation pattern of the antenna significantly as compared to when it is located at the center [15]. The edge-to-edge distance between the shorting pin and the feeding point is 4 mm for both antennas at 2.4 GHz and 5.8 GHz. The distance helps in tuning the matching of the antenna, and is determined by doing parametric study.

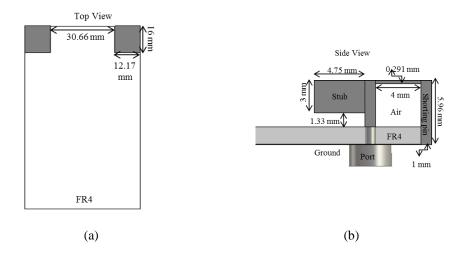


Figure 2. The design view of 5.8 GHz MIMO antenna showing (a) top view and (b) side view

The antenna elements are made up of copper with the thickness of 0.291 mm. The size of the antenna elements at 2.4 GHz is 12.17(W)x16(L) mm², while the size of the antenna elements at 5.8 GHz is 4.25(W)x11(L) mm². These sizes are determined by a quarter wavelengths of 2.4 GHz and 5.8 GHz, respectively. The distance between the antenna elements and substrate controls the bandwidth of the antennas and also critical in deciding antenna's overall performance [10]. At 2.4 GHz, the distance is at 5 mm while at 5.8 GHz, the distance is at 4 mm. At higher frequency, a stub with the dimension of 4.75(W) x 3(L) mm² is

added to improve the matching of the antennas. The detailed dimension of the both antennas can be seen in Figure 1 and Figure 2.

After the optimization of the antenna, the proposed antennas are then fabricated and measured. Figure 3 and Figure 4 show the fabricated prototype of the antennas. The antenna at Port 2 is symmetrically identical to antenna at Port 1 for both MIMOs. Two $50~\Omega$ coaxial feed are utilized, and the outer conductor of the coaxial feeds are connected to the ground plane and the inner conductors are used to feed the PIFAs at the feeding pin positions.



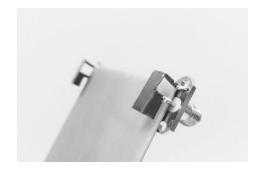


Figure 3. Fabricated prototype of MIMO antennas at 2.4 GHz

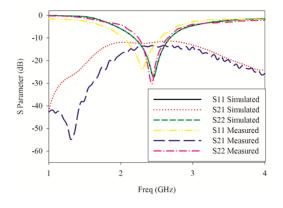
Figure 4. Fabricated prototype of MIMO antennas at 5.8 GHz

3. RESULTS AND ANALYSIS

3.1. Scattering parameters for 2.4 GHz and 5.8 GHz two-port antennas

Upon the full optimization of both antennas via simulation using microwave studio of computer simulation technology (CST), a set of final dimensions are obtained (see Figure 1 and Figure 2). The proposed antennas are then fabricated which can be seen in Figure 3 and 4. Figure 5 and Figure 6 show the simulated and measured S parameters (S_{11} , S_{22} , S_{21}) for the MIMO antennas. The simulated S_{11} for the antenna operated at 2.4 GHz shows a bandwidth of 0.51 GHz from 2.18 to 2.69 GHz. However, discrepancies in measured results are found due to the fabrication inaccuracy. Measurements indicated that a band of operation have a bandwidth of 0.5 GHz from 2.2 to 2.7 GHz which fulfills the requirements for Wi-Fi band.

The simulated S₁₁ bandwidth for the 5.8 GHz antenna is 1.61 GHz from 4.81 - 6.42 GHz. The measurements have also been performed for 5.8 GHz antenna in which a slightly less bandwidth of 1.46 GHz is achieved due to the fabrication inaccuracy and covers band from 4.98 to 6.44 GHz which covers the whole frequency band of WLAN application. The isolation for both antennas 2.4 and 5.8 GHz band is within the limits of -10 dB. Due to the symmetrical arrangement of the antennas, the measurement results for S-parameters for both antennas are almost identical as can be seen in Figure 5 and Figure 6.



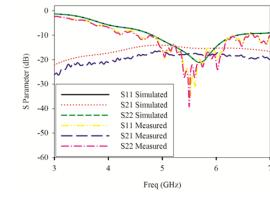


Figure 5. Simulated and measured S-parameter of MIMO antenna system for Wi-Fi mobile application at 2.4 GHz

Figure 6. Simulated and measured S-parameter of MIMO antenna system for WLAN mobile application at 5.8 GHz

3.2. Effects of user's hand on 2.4 GHz and 5.8 GHz two-port antennas

In a typical usage scenario the user holds the mobile terminal and therefore, degradation in the performance of the antenna can be avoided if the effect of the immediately located hand is taken into account. Normally, user holds the mobile in a widely variable way and the degree of the hand impact depends on the antenna (size, design, near field distribution and location) and the grip (position of the finger on the antenna, obstructed antenna area and palm-handset distance). However, the implementation of more than one antenna gives opportunity if the user significantly affects one of them, and the other one can be utilized.

Antenna in mobile application is associated with the interference of user's effect. The dielectric loading of the user's hand often cause the deterioration in terms of impedance mismatch and efficiency of the antenna. Time domain solver of CST microwave studio is used for full wave simulations of the terminal prototype and user hand. SHO3TO6-V3 left hand phantom ($\varepsilon r=22.5$) is used for the analysis of impedance bandwidth and radiation efficiency [16]. From the Figure 7 it is clearly shown that the index finger is pointed towards the one of the antenna. However, another antenna is still in free space and unobstructed by user's finger. Similarly, if left hand is used the results should be vice-versa. Due to the symmetry of the antenna elements only results for right hand is shown (see Figure 7 (a) and (b)).

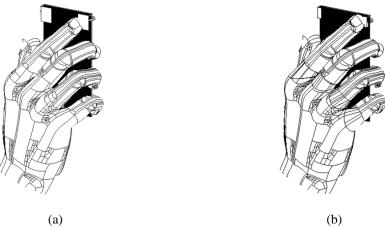
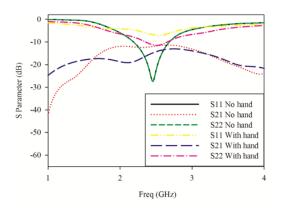


Figure 7. Hand phantom (a) with MIMO antennas at 2.4 GHz. (b) with MIMO antennas at 5.8 GHz

The effects of user's right hand on antenna scattering parameters are shown in Figure 8 and Figure 9. An upwards shift of 0.17 GHz were observed when the user's hand index finger is placed exactly on top of the antenna at 2.4 GHz and 5.8 GHz as shown in Figure 8 and Figure 9, respectively. This is due to the dielectric loading of finger on antenna is one of the reasons of resonant frequency mismatch.



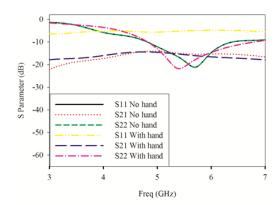


Figure 8. S-parameter study on MIMO antenna at 2.4 GHz with and without hand phantom

Figure 9. S-parameter study on MIMO antenna at 5.8 GHz with and without hand phantom

An important parameter in characterizing antennas is its efficiency. As the absorption in the human tissue decreases the efficiency, this factor relates directly to the potential health risks. This is due to the losses in the medium which affects the wave in the far-field region as it attenuate more rapidly and finally to zero [17]. Table 1 shows the bandwidth and total efficiencies of the MIMO antennas with and without hand phantom. It can clearly be seen that the efficiencies of the antennas degrade when the hand phantom is in close proximity to antenna element. The clear difference of total efficiency between two antennas (2.4 and 5.8 GHz) can be seen from Table 1. This is due to the different sizes of both antennas. For 2.4 GHz antenna size is relatively bigger than 5.8 GHz. This is why the user's hand index finger covers more area in result more energy is absorbed to the human hand, whereas for 5.8 GHz antenna the index finger does not cover the antenna so much. That is why the energy absorb to the user's index finger is less and the antenna can still be able to radiate about 45.58 % of its energy. The bandwidth of the antennas is also found slightly shifted to higher frequency.

Table 1. The comparison of performance of MIMO with and without hand phantom

Antenna	Bandwidth GHz (free space)	Bandwidth GHz (with hand)	Eff _{total} (free space)	Eff _{total} (with hand)
2.4 GHz	2.18-2.69	2.35-2.66	P1: 92.97% P2: 92.97%	P1: 11.41% P2: 25.76%
5.8 GHz	4.81-6.42	4.98-6.44	P1: 94.53% P2: 94.53%	P1: 45.58% P2: 84.88%

4. CONCLUSION

In this paper, two MIMO antennas made up of symmetrical PIFAs have been presented. These MIMO antennas working frequencies are at 2.4 GHz and 5.8 GHz. A detailed description and discussion of the MIMO antennas and their performances have been included and the effects of hand on MIMO have also been studied and presented. Both of the antennas have been fabricated and measured results are in good agreements. It is seen that an upward shift of 0.17 GHz is found at 2.4 and 5.8 GHz in impedance bandwidth in the presence of user's hand. It is also found that antenna sizes matter a lot for mobile terminal application as in this case the size of antenna at 2.4 GHz is bigger so that the user's hand covers most of the antenna in results more energy is absorbed as compare to the 5.8 GHz antenna which is smaller and the user's hand does not obstruct the results so much. The antenna prototype measurements results using a realistic hand phantom model will be presented in future.

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348 🗖 ISSN: 2302-9285

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Rizwan Khan was born in Abbottabad, Pakistan in 1990. He received a degree of MS in Electrical Engineering from COMSATS Institute of Information Technology, Abbottabad, Pakistan in 2015 and the PhD Communication Engineering from Universiti Malaysia Perlis (UniMAP), in 2018. Form 2015 - 2016, he served COMSATS as Research Associate in the Department of Electrical Engineering. He has published several impact factor journals, national and international conference papers. He is currently a researcher at Advanced Communication Engineering (ACE) in UniMAP, Malaysia. His research interests include mobile terminal antennas and their user interactions, MIMO antennas, dielectric resonator antennas, metamaterial, electrically small antenna and reconfigurable antennas.