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User's hand effect on efficiency of 2-port 5 GHZ mobile terminal antennas

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ABSTRACT

In this paper, the influence of user's hand on mobile terminal antenna when it placed approximately on top of Multiple Input Multiple Output radiating element antennas (PIFAs) is studied extensively. The antenna is designed to operate at 5 GHz with 1.5 GHz of -6 dB bandwidth. The effect of user's hand with different finger positions are studied at seven positions on slit at the ground plane, seven differences height above the antenna and nine different locations around the radiating element at 2 mm height from antenna. The losses due to presence of hand are studied in terms of scattering parameters, radiation efficiency and matching efficiency. The maximum loss in term of isolation in the presence of user's hand is found at 6 mm on the slit and it decreased as the hand move away from the slitted area on the ground plane. The maximum efficiency loss is observed when the finger is placed right on top of the radiating element with -5.85 dB compare to antenna without the presence of user's hand. On the other hand, the result for matching efficiency indicates approximately 0.2 dB losses occurred when the fingers are varied at different height and position.

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1. INTRODUCTION

The rapid growth of cellular communication the demand for a wider bandwidth at higher frequency is also growing which able to provide high data rates transmission. This is also needed in order to support various audio-visual services especially regarding to fifth generation (5G) technology. In order to resolve the problem, the planar inverted-F antenna (PIFA) is used due its advantages of ease in fabricate, low profile, low cost, light weight, and provide reliable performance [1, 2]. Thus, the usage of PIFA as antenna in multiple input multiple output antenna (MIMO) system will be a great solution. This is because the MIMO system is able to enhance the channel capacity with no need of additional bandwidth or transmitting power [3].

It is a huge challenge for RF engineer in designing a compact and small size mobile terminal antenna. This is because the mobile terminal antenna designer needs to follow the device set boundaries of predetermined positioning and volume of the antennas. Besides the antenna properties itself, the investigation on user's effects is the unavoidable alteration performance occurred when user is in close vicinity to the mobile terminal antenna [4-7]. The broad understanding from the effect of the user's head [8] motivate and excite the concern on user's hand effects studies. Most of the researches studies the different of hand grips and hand positions in several frequency ranges at cellular bands lower than 3 GHz (700 MHz, 1750 MHz, etc.) [9, 10] and above 10 GHz (15, 28 and 60 GHz) [11-14]. It is found that the typical area of user's finger location literally near to the antenna and at the back of mobile terminal. Besides that, the resulting absorption loss varies depending on the frequency because for the different frequencies, user's hand exhibits different permittivity [15]. Due to the fact, that human skin behaves different in different frequency because the penetration depth is changed with the change in frequency band. For the first time, to the best of authors' knowledge, this analysis is performed in term of antenna scattering parameter, radiation efficiency and matching efficiency using user's hand for 5 GHz (sub-6 GHz 5G) [16] frequency band for mobile terminal antenna.

In this paper, the effect of user's hand with different finger positions on mobile terminal antenna performance at sub-6 GHz 5G band is investigated by using simulations. Firstly, the design of antenna is presented then followed by the effect of user's hand on: 1) antennas reflection coefficient and isolation performance; 2) radiation efficiency and matching efficiency of the antenna depend on user's finger index location. Finally, the concluding remarks will be shown at the end of paper.

2. ANTENNA CONFIGURATION

The proposed simulated mobile terminal antenna structured in this paper is shown in Figure 1. The terminal consist of two symmetrical PIFAs with the concept of the design, based on optimized rectangular radiating element with a shorting pin and feeder. Both of the antennas were placed at the end of substrate and are optimized to operate at 5 GHz resonant frequency with 1.5 GHz bandwidth (30%) below -6 dB. The Rogers RO4003C is used as the substrate with a dielectric constant of 3.38, loss tangent of 0.0027 and thickness of 0.813 mm. Both of the radiating element and their shorting pins and feeders labelled as port 1 and port 2 respectively as shown in Figure 1(a). The copper plate with thickness of 0.508 mm is used as the radiating element with the size of 3.5×8 mm^2 (width×length). Both of feeders (2×5.5 mm^2) and shorting pins (0.5×6.4 mm^2) are made from the same copper plate as the radiating element. The distance between radiating element 1 and radiating element 2 is 35 mm and the height of both radiating elements from the top of substrate is 5 mm. A 50 ohm transmission line (2 mm width) is placed on top of substrate, below the radiating element as illustrated in Figure 1(b). The connectors itself were used as via to connect the transmission line and ground plane. The two edge of transmission line as depicted in Figure 1(c) were chamfered about 2 mm for frequency tuning. A full rectangular (55x110 mm^2, width×length) ground plane with slit ($\lambda/4 \times 0.033\ \lambda$) on it is used for the terminal. The slit is used to improve the isolation between both antennas [17]. In order to represent the accurate human hand in this simulation, the CTIA standards homogeneous hand phantom was chosen. It is made up by lossy dielectric material with permittivity of 22.2 and conductivity of 2.48 S/m at 5 GHz [18, 19].

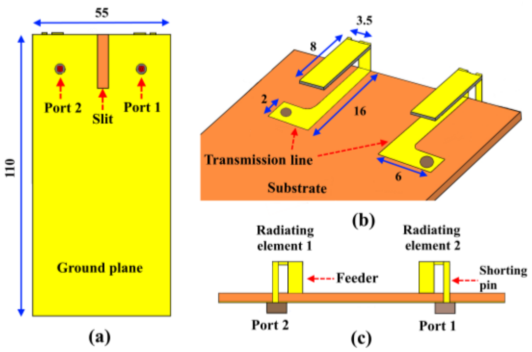


Figure 1. Antenna configuration with dimension, all dimension are in millimeter

All simulations process were performed using the time domain solver of CST Studio Suite ®, microwave studio software. Figure 2 shows the S-parameters of the proposed antenna in free space (FS). The reflection coefficient (S_{11} and S_{22}) are identical for both PIFA antennas at free space (FS), as a result of symmetrical antenna elements. The results in Figure 3(a) and Figure 3(b) show that at 5 GHz the impedance bandwidth is 1.5 GHz below -6 dB while the isolations (S_{12} and S_{21}) is below -13 dB. For investigation of user's hand effect on isolation, seven different positions of user's hand finger were set on the slit at the ground plane along the y-axis as shown in Figure 4. The user's hand starts to move from position at 0 mm until 18 mm with gap of 3 mm for every step. Due to the concision, the results that have been found almost similar such as at position 0, 9 and 15 mm are not shown here.

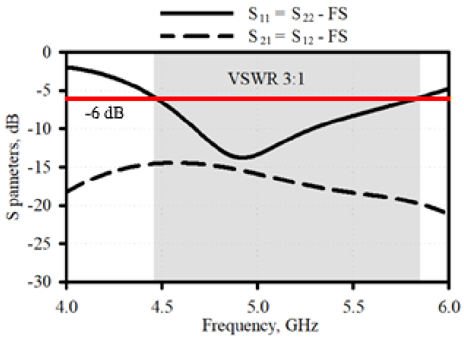
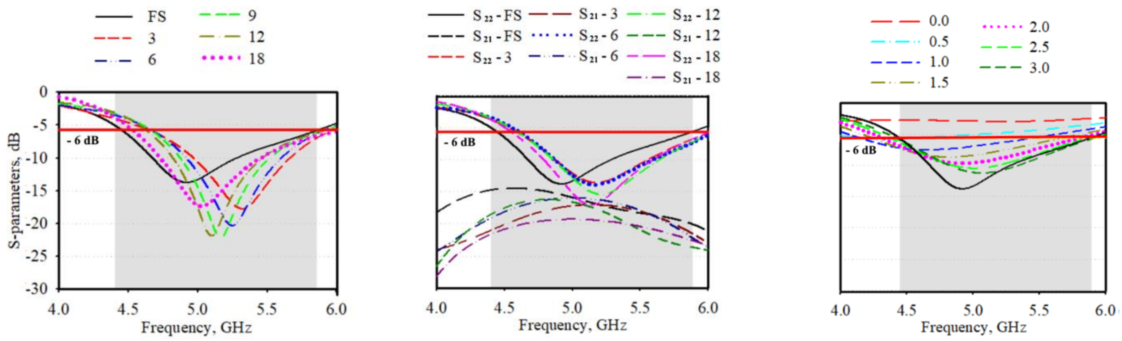


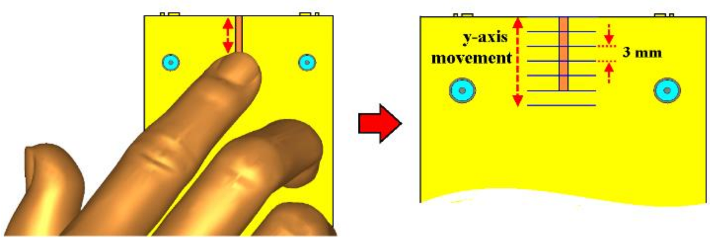
Figure 2. S-parameters of proposed antenna in free space (FS), the straight red colors indicated -6 dB

The isolation for all steps were recorded and illustrated as in Figure 3(b). It is observed that the minimum value of isolation is shown in the middle of the slit which is at 6 mm (-15.94 dB) and better isolation when the hand is shifted downwards of slit until it reached out of λ/4 distance. This is due to no interruption for current distribution from user's hand on the slit. Meanwhile, Figure 3(c) shows the effect of user's hand index finger when it is placed on top of radiating element. It is found that as the finger is further away from the radiating element the matching level is improved as much as 0.02 dB accordingly. These improvement are observed uniformly above 2 mm height. Therefore, the distance at 2 mm between user's hand and radiating element 2 is chosen for further analysis at 5 GHz resonant frequency.



(a) (b) (c)

Figure 3. S-parameters of the proposed antenna, (a) S_{11} for free space (FS) and distance at slit on the ground plane starting from 0 mm to 18 mm, (b) S_{22} and S_{12} for free space (FS) and distance at slit on the ground plane starting from 0 mm to 18 mm, where, S_{21}=S_{12}, (c) S_{22} for user's hand varies at different height above the radiating element 2 starting from 0 mm until 3 mm



(a) (b)

Figure 4. User's hand set up on the top of slit at the ground plane, (a) user's finger pointed on the slit at the ground plane, (b) movement of the hand from 0 mm to 18 mm out of the slit area

3. RESULTS AND ANALYSIS

3.1. Radiation efficiency

The deterioration of antenna performances can be avoided if the user's hand affect are considered during the designing stage of mobile terminal antenna. The effects of user’s hand are varied depends on the way of users hold the mobile terminal. Also, the impact can be influenced by the antenna design, compactness, size, location and near-field distribution. As well as the user’ hand grip or position with respect to the antenna, mobile terminal distance and blocked antenna area. The use of more than one antenna known as MIMO, enables the usage of another antennas if the intended one affected by user’s hand. Therefore, a hand phantom with ε_r=22.2 at 5 GHz is used to represent the real human hand for the simulation process.

The user’s finger with whole hand was placed at 2 mm on the top of antenna elements 2 as depicted in Figure 5. For parametric study, the hand was varied from the top of antenna element 2 (0 mm position) up to 3 mm along z-axis. Then, from the results, nine different user’s hand with finger index of 3.5 mm (x-axis)×2.7 mm (y-axis) locations placement was set and labelled as A to C (column) and D to F (row) for x-axis and y-axis, respectively as shown in Figure 6. The deviation of antenna impedance bandwidth, antenna impedance matching, radiation efficiency and matching efficiency are investigated as the distance and location are varied.

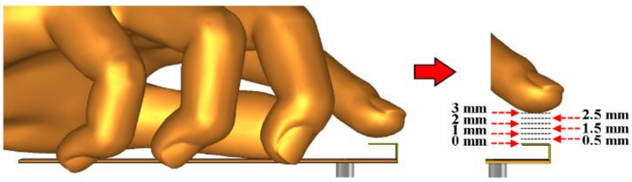


Figure 5. User’s hand set up on the top of radiating element 2 for height variation

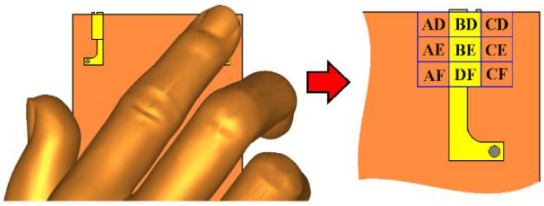


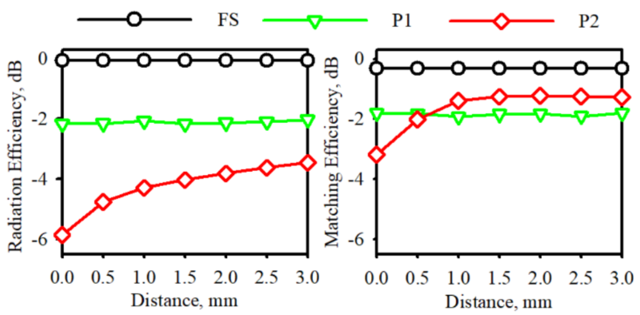
Figure 6. User’s hand set up at 2 mm height with the movement direction at x-axis and y-axis

One of the significant parameter in describing the antenna characteristic is the efficiency. Typically, the accuracy of antenna efficiency determined by using full wave simulators but it is no longer forthrightly because of the losses in mismatch or material [10]. It also due to the inaccuracy of method used in pattern computation. This is happened when the losses in material affected the wave in far-field region by way of weaken more rapidly and lastly lead to zero.

The primary target of this study is to investigate the behavior of radiation efficiency. This is done by placing the human hand index finger on the top of radiating element at nine different locations. Figure 7(a) shows the average radiation efficiency at port 1 and port 2 for seven different heights along the z-axis from 0 mm to 3mm heights. It can be seen that the value of radiation efficiency is increase slightly with the increase of distance of user’s hand index finger from the antenna element. However, from 2 mm onwards a less increment value of improvements are examined. Therefore, this is one of the reasons to choose 2 mm distance between antenna and user’s hand for this analysis. Beyond this distance, the losses of near-field in the hand become irrelevant. In Figure 8(a), it illustrates the average of radiation efficiency when the index finger of hand is located at 2.0 mm on top of radiating element 2 at nine different locations which are AD to AF, BD to DF and CD to CF as shown in Figure 5. The average radiation efficiency is calculated for each MIMO antenna where the average values have been taken over the whole bandwidth of each antenna. The user’s hand index finger is varied along the x-axis and y-axis with the distance of 3.5 mm and 2.7 mm, respectively. As depicted, the value of FS (without hand) is –0.07 dB due to low losses substrate of RO4003C. The deviation of columns A, B and C seems to be uniform at port 1 which is -0.2 dB and -0.1 at port 2 at a distance of 2 mm between index finger and radiating element.

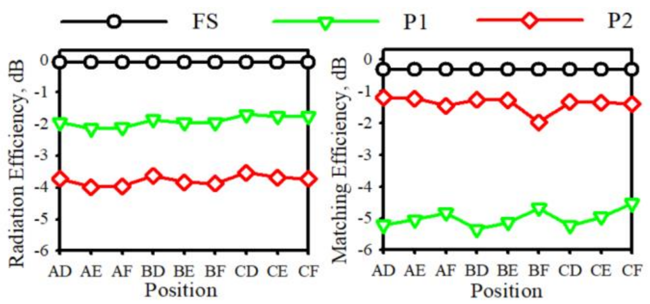
3.2. Matching efficiency

The simulated average matching efficiency result at port 1 and port 2 for seven distances along z-axis and nine different locations along xy plane in fixed height of 2 mm are depictedin Figure 7(b) and Figure 8(b), respectively. Similarly, the average of matching efficiency is calculated which is taken over the whole bandwidth of each antenna. In Figure 7(b), it shows that the value of matching efficiency is rapidly increased when the height increased until it reached to 2 mm distance. From this point onwards, only small value of improvement is obtained similar to the radiation efficiency. In the other hand, Figure 8(b) portrays the average matching efficiency for each different locations of user's hand index finger at the same height (2 mm). Here, it can be observed that the deviation is uniform for both port 1 and port 2 which is -0.2 dB but at position BF, matching efficiency slightly fluctuates due to the position of finger is near to the input port.



(a) (b)

Figure 7. Average efficiency for port 1 and port 2 for 0 mm to 3 mm, (a) Radiation efficiency, (b) matching efficiency



(a) (b)

Figure 8. Average efficiency for port 1 and port 2 at 2 mm with different location, (a) Radiation efficiency, (b) matching efficiency

4. CONCLUSION

In this paper, the effect of user's hand with different finger positions on the mobile terminal antenna that operate at 5 GHz is studied. It can be concluded that the isolation between two PIFAs is observed to give a minimum value when the user's hand located exactly in the middle of $\lambda/4$ slit and the isolation improved when the hand move away the slit area on the ground. For the radiation efficiency, a uniform increment is found when the user's hand reach at 2 mm height from above the antenna element. While the distance varies only give a slightly affect to the matching efficiency. From this study, it is also observed that to get a better result for radiation efficiency, reflection coefficient and isolation, the user's hand index finger should at least have a gap from the antenna element at 2 mm onward. This can be applied when the casing of the mobile terminal will be implemented. Also the fabrication and measurement with real hand phantom are planned for future work.

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