Dual Monopole Frequency Reconfigurable Antenna for MIMO 5G sub-6 GHz Mobile Terminal

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Abstract. In this paper, a Dual Monopole Frequency Reconfigurable Antenna (DMFRA) for two port Multiple Input Multiple Output (MIMO) Fifth Generation (5G) sub-6 GHz mobile terminal is presented. A combination of dual monopole strips is implemented at a port, respectively to achieve tunable and fixed resonant frequencies. Varactor diode is utilized in this design to perform the frequency reconfiguration. Dual tunable resonant frequencies at the lower band (1690 MHz to 2200 MHz) and higher band (4400 MHz to 5400 MHz) are created by the monopole branch which accommodates the varactor diode. On the other hand, a fixed frequency band at 2400 MHz with -10 dB bandwidth of 450 MHz is achieved by another monopole branch without variable diode. Maximum realized gain achieved at both lower and higher reconfigurable frequency bands and fixed frequency band are 2.73 dB, 3.8 dB and 2.57 dB, respectively. Besides that, high isolation between 2 DMFRAs decreases the mutual coupling to result in less than 0.1 of the Envelope Correlation Coefficient (ECC). In addition to its frequency reconfiguration capability and low ECC, the proposed MIMO antenna is considered suitable for potential 5G mobile terminal applications.

Keywords—5G Sub-6GHz; mobile terminal; MIMO; monopole antenna; frequency reconfigurable

1. Introduction

The Long-Term Evolution (LTE) and LTE-Advanced (LTE-A) bands introduced in the Fourth Generation (4G), has a strong demand to produce greater channel throughput and better reliability [1]. Furthermore, the utilization of Multiple Input Multiple Output (MIMO) technology in the 4G communication system has proven its ability to further increase the wireless channel throughput without additional spectrum [2]. However, the bandwidth allocated for LTE and LTE-A bands are getting denser in the recent years, since the usage of smartphones in our society is rapidly growing [3]. Therefore, the new Fifth Generation New Radio (5G-NR) cellular bands operating at sub-6 GHz bands and millimeter
wave bands has been released by 3rd Generation Partnership Program (3GPP) overcome the band limitation issues [4] [5].

Telco industries are preparing to adopt these new frequency bands into mobile terminals to enhance their services to produce high quality video streaming, audio/video calls, online gaming and etc. Nevertheless, it has become an obstacle to integrate multiple antennas due to space constrain on the mobile terminals [6]. Existing cell phones are facing significant disadvantages related to mutual coupling issues, due to the integration of the MIMO system and multiple antenna elements to support several wireless communication protocols [7] [8]. In addition, accommodating additional antennas to embrace 5G-NR cellular bands in space-limited mobile phones would increase inter-antenna mutual coupling, thus degrading the efficiency of the channel throughput [9]. If not carefully implemented, positioning multiple antennas with inadequate spacing, results in an increase in mutual coupling, which then effects the efficiency of the channel throughput [10]. Therefore, optimizing the space utilization in mobile phones is extremely needed to fulfill the wireless communication requirements. One of the effective solutions for preserving lower mutual coupling is to ensure the integrated antennas to operate in dual or multi-bands [11] [12]. Moreover, including the frequency reconfiguration feature on these antennas will be added as promising advantage to realize the 5G communication needs [13]. Such a feature enables the mobile phones to have multi band coverage in both 4G and 5G, without altering the antenna’s physical structure and the size of the mobile terminal, while retaining lower mutual coupling on mobile terminals. Reconfigurable Antennas (RAs) are becoming highly demand due its flexibility in reconfiguring antenna’s frequency, radiation pattern and polarization. Thus, it is a benefit for mobile phones to replace the traditional antennas with RAs in MIMO antenna system, to operate at multiple bands and improve the data transmission in rich scattering environment.

In this paper, we proposed a Dual Monopole Frequency Reconfigurable Antenna (DMFRA) for two port MIMO 5G sub-6 GHz mobile terminal application. The unique feature of this design is the ability to use dual monopole strip concept within a single port, respectively to achieve tunable and fixed resonant frequencies. Varactor diode is utilized to perform the frequency reconfiguration. The monopole branch that accommodates the varactor diode, generates dual tunable resonant frequencies at lower band (1690 MHz to 2200 MHz) and upper band (4400 MHz to 5400 MHz). On the other hand, a fixed resonance is achieved at 2400 MHz with -10 dB bandwidth of 450 MHz by the monopole structure without varactor diode. The proposed antenna has achieved good isolation (> 10 dB) and lower envelope correlation coefficient (< 0.06). In recent years, several frequency reconfigurable antenna designs have been proposed for MIMO mobile terminal applications. However, the antenna designs presented in [6], [7], [9]-[17], are unable to provide coverage for the 5G sub-6 GHz bands. Moreover, the antenna presented in [18] is only capable to provide coverage for 5G bands in millimeter wave regions (< 24 GHz). This is the first two port frequency reconfigurable MIMO antenna design to the best of our knowledge, which accommodates dual monopole antenna strips within a single port, operating at the frequency band of LTE, LTE-A and 5G sub-6 GHz. This paper is divided into four sections. The introduction is Section I. The design details of the suggested antenna are listed in section II. The simulated outcomes are evaluated and discussed in section III. Finally, conclusion is presented in section IV.

2. Antenna Design Configuration

Figure 1 shows the proposed two port DMFRA. CST Microwave Studio software is used in this research work to design and simulate the antenna. As shown in Figure 1(a), two DMFRA elements comprises of same dimension were placed on the top right and left side of the RT 5880 substrate with the dimension of 110mm x 55mm x 1.575mm. Two ground plane structures with the size of 20mm x 24mm x 0.035mm is attached on the bottom layer of the substrate as illustrated in Figure 1(b). SMA connectors are placed on the ground plane, respectively on port 1 and 2. A transmission line with the dimension of 18mm x 4mm x 0.035mm distributes the RF current into Monopole Branch 1 (M1) and Monopole Branch 2 (M2), respectively, as shown in Figure 2(a). M1 which has a dimension of 29mm x 4mm x 0.035mm, consists a varactor diode and Direct Current (DC) supply to tune the resonant frequencies produced on this structure. On the other hand, M2 with the dimension of 18mm x 4mm x 0.035mm is constructed without varactor diode to produce a fixed resonant frequency. Figure 3 shows the DC biasing circuit for the varactor diode attached on M1 at port 1.
The geometry of the propose antenna. (a) Terminal front view (b) Terminal rear view (c) and (d) Dimension details of QPIFA (e) QPIFA rear view (SMA). All dimensions are in millimeter (mm).

Figure 1. The geometry of the propose antenna. (a) Terminal front view (b) Terminal rear view (c) and (d) Dimension details of QPIFA (e) QPIFA rear view (SMA). All dimensions are in millimeter (mm).

Figure 2. The geometry of the propose antenna. (a) Terminal front view (b) Terminal rear view (c) and (d) Dimension details of QPIFA (e) QPIFA rear view (SMA). All dimensions are in millimeter (mm).
Figure 3. The biasing circuit for varactor diode attached on M1 at port 1.

From the figure, it can be seen that the capacitance of the varactor diode varies as the input voltage is supplied to M1 in reverse bias condition. As a consequence, an alteration of the M1 capacitance is ensued, which causes variation on the resonant frequencies. In addition, a 5pF capacitor is mounted on M1 to prevent the DC voltage from entering the Radio Frequency (RF) source. On the other hand, 1 µH inductor is mounted on the bottom layer to suppress the RF current from entering the DC voltage supply. S2P files of the Skyworks SMV1232-079 varactor diode model was used in this simulation, as shown in Figure 1(a). SMA connectors have been mounted on the ground plane surface to feed the RF source to both port 1 and port 2 of DMFRA, as shown in Figure 2(b). Inductors were placed at the supply and grounding point of DC voltage to disallow the RF current from damaging the DC voltage supply.

3. Result and Discussion

The simulated scattering parameter (S-Parameter) of the MIMO DMFRA structure is illustrated in Figure 4. From the obtained result, we can notice that the DMFRA has achieved triple bands as shown in Figure 4(a). M1 from both ports, has achieved six resonant states at both lower and higher band through the variation of the input voltage from 0V to 5V. The resonance at lower band is varied from 1690 MHz to 2200 MHz, with -10dB bandwidth of 510 MHz. In addition, the resonance at higher band is achieved from 4400 MHz to 5400 MHz, with -10dB bandwidth of 1000 MHz. On the other hand, M2 has achieved a fixed resonance at 2400 MHz band with -10 dB bandwidth of 450 MHz. The transmission coefficient, S12 or S21 between two DMFRAs of less than -10dB, shown in Figure 4(b) indicates the achievement of a low mutual coupling. We achieved lower coupling results by using separate ground planes for both ports, resulting in uncorrelated RF currents. The details of the covered cellular bands are listed in Table 1. The two-dimensional radiation pattern results of DMFRA monitored at both ports at xz-plane and xy-plane are respectively shown in Figure 5 and Figure 6. In order to analyse the radiation pattern and the realized gain, three frequency points were chosen from the reconfigurable and fixed resonant frequencies, respectively. The maximum realized gain achieved at 1900 MHz, 2400 MHz and 5000 MHz for both ports are 2.73 dB, 3.8 dB and 2.57 dB, respectively. Thus, we can see that this antenna has achieved good gain at both reconfigurable and fixed resonant frequencies, despite the utilization of separate ground plane.
The scenario of achieving these bands can be explained further with another function known as Surface Current Distribution (SCD). Figure 7 illustrates the SCD monitored at port 1 at the specific resonant frequencies. We can clearly note from the figure that the RF current is distributed during the achievement of tunable and fixed resonant frequencies along the respective monopole branch. As depicted in Figure 7 (a) and (b), the RF current is distributed along M1 during the initiation of the resonance at both lower and higher bands, respectively. Concurrently, frequency reconfiguration is performed at these frequency bands due to the presence of varactor diode. Figure 7(c) on the other hand, illustrates the RF current distribution along M2 which was monitored at fixed 2.4 GHz band. From these figures, we can observe that the RF currents are mainly distributed only on the respective monopole branches during the achievement of tunable and fixed resonant frequencies.
Table 1. The IFA element configuration at both ports

| Activated IFA Elements | Ports | Frequency achieved (MHz) | -10 dB Bandwidth (MHz) | Cellular Bands |
|------------------------|-------|--------------------------|------------------------|----------------|
|                        | Port 1 | 1690 ~ 2200              | 510                    | LTE Band 1, 2, 3, 4, 25, 34, 37, 39, 65, 66 & 70 |
| M1                     | Port 2 | 4400 ~ 5400              | 1000                   | 5G NR Band n80, n84, n86, n95 |
|                        | Port 1 | 2300 ~ 2750              | 450                    | LTE Band 7, 30, 38, 40, 41, 53, 69 |
|                        | Port 2 |                          |                        | 5G NR Band n90 |

Figure 5. The radiation pattern (xz-plane) monitored at port 1 and 2 at (a) 1900 MHz (b) 2400 MHz and (c) 5000 MHz.

Figure 6. The radiation pattern (xy-plane) monitored at port 1 and 2 at (a) 1900 MHz (b) 2400 MHz and (c) 5000 MHz.
Figure 7. Surface current distribution monitored at port 1 at (a) 1.9 GHz, (b) 5 GHz (c) 2.4 GHz.

Figure 8. The simulated ECC result between port 1 and 2.

The simulated Envelope Correlation Coefficient (ECC) between two DMFRAs is depicted in Figure 8. ECC is a measurement to calculate the correlation performance between MIMO antennas. The MIMO antenna system is capable of achieving low correlation and good output diversity if the ECC value is less than 0.5. As shown in the Figure. 8, the ECC values achieved between the two DMFRAs in the resonant bands are lower than 0.1. This indicates that the antenna elements are almost uncorrelated to each other.

4. Conclusion

DMFRA is formed by combining dual monopole antenna strips, respectively to achieve tunable and fixed resonant frequencies. The M1 that accommodates the varactor diode has achieved six resonant states through the variation of input voltage from 0V to 5V, thus generating dual tunable resonant frequencies at lower band (1690 MHz to 2200 MHz) and upper band (4400 MHz to 5400 MHz). On the other hand, the M2 without varactor diode has achieved fixed resonance at 2400 MHz with -10 dB bandwidth of 450 MHz. The proposed antenna has achieved good isolation (> -10 dB) and lower envelope correlation coefficient (> 0.1). The radiation patterns of DMFRA that were monitored at 1900, 2400 and 5000 MHz bands achieves good gain. The ability of this MIMO DMFRA to cover several LTE, LTE-A and 5G sub-6 GHz bands while achieving a lower ECC indicates that this proposed design is very suitable for 5G mobile terminal applications.
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