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SUMMARY AND CONCLUSION

Now-a-days, in mobile communications systems, quality of services with high data rate is demanding. To fulfil the current demand of mobile communication market, introduction of Multiple Input Multiple Output (MIMO) antenna systems have drawn a great attention. The MIMO systems provide effectiveness in channel capacity without requiring more spectrum efficiency and power. In an environment with strong fading, a multiple antenna system can usually be used as MIMO mode or diversity mode according to the SNR level of the signals. In high SNR environment, the MIMO mode will be active and channel performance will be studied. In the low SNR environment, diversity mode will be chosen. The diversity is a promising, integrated, and well known technique in the new generation of wireless communication systems. With the antenna diversity technique, the multipath fading problems can be overcome, and furthermore better signals performance can be obtained, both in high data rates and low error rate. In order to achieve diversity, multiple antenna systems are deployed inside the mobile phones which help to mitigate the multipath fading and provide better quality of services. However, in the mobile handsets, availability of space inside the mobile phones is limited. Therefore, compact and multiband antenna structure with MIMO configuration to fulfil the demand of better quality of communication, high data rates, and multifunctional operation are developed.

In this thesis, there are seven chapters with summary and conclusion. The entire investigations have been focused on design and development of MIMO/Diversity antenna for mobile handsets. The investigation have been done sequentially, start from dual band PIFA structure to wideband planar monopole antenna for next generation mobile phone applications. The proposed isolation enhancement technique is applied to enhance the mutual coupling between MIMO antenna elements. The performances of MIMO/Diversity antenna are also investigated in actual scenario of mobile phones. Further, user proximity is considered to check the robustness of MIMO antenna elements.

The brief historical review of electromagnetic and road map of MIMO technology are studied initially followed by the operation of MIMO technology including calculation of channel capacity of MIMO antenna system. There are various promising antenna structure (planar inverted-F antenna and planar monopole antenna) are available for next generation mobile phones. The theoretical background, design concept, radiation mechanism, and advantages of these antenna structures are elaborated. The MIMO configuration are deployed inside the mobile devices using compact PIFA and PMA by placing more than one antenna on same ground plane of PCB of mobile circuit board. In the case of multi antenna system, the isolation between antenna elements are crucial parameter within small mobile devices. There are different isolation enhancement techniques available in the literature and discussed sequentially. The brief discussion of MIMO technology, isolation enhancement techniques, and available literature related to the MMO/Diversity antenna system are given in the opening chapter.

When multi antenna systems are deployed inside the mobile devices, performance evaluation of multi antenna system is also important. There are various diversity parameters and MIMO parameters considered and studied for multi antenna system. In the diversity parameters such as ECC, MEG, and EDG are described with defined limit whereas MIMO parameters such as MIMO channel capacity and multiplexing efficiency are discussed. After successful characterization of MIMO/Diversity antenna in free space, it is necessary to place the designed multi antenna system in actual mobile environment with close to user proximity and characterized the MIMO antenna. To check the SAR distribution inside the human head phantom simulation setup is created according to the CTIA standard in CST MWS. The SPLSR is calculated for MIMO antenna system and TRP is also investigated.

The design and analysis of highly isolated dual-band MIMO/Diversity antenna is presented. A low profile MIMO antenna is designed and fabricated by the use of 0.2mm thick copper plate. MIMO antenna structure consists of two symmetrical back-to-back PIFA elements, which are located on top two corners of the FR4 substrate. Each element comprises of two radiating arms (main arm and side arm) resonating at 2.45 GHz and 5.5 GHz frequencies respectively. By taking into account of mobile space, the main radiating arm is folded and initially it is resonating at 2.75 GHz. In order to resonate at desired frequency (2.45 GHz) two slots are loaded on the top patch plate which increases the electrical length of radiator and hence the resonant frequency decreases from 2.75 to 2.45 GHz. The side radiating arm is bent vertically along to main arm so as to occupy less space to achieve the compactness of antenna element within $12 \times 9 \times 6$ mm^3. To enhance the isolation between folded PIFA elements, a folded shorting strip is proposed to avoid the current flow from port1 to port2 so that low mutual coupling can achieve. The current loop starts from shorting strip and next to ground plane and next to folded shorting strip and towards feed point which leads the high isolation between MIMO antenna ports. The performance of the dual-band PIFA is also experimentally verified. Further, actual scenario of mobile environment is considered around the MIMO antenna elements due to which reflection coefficient is deviated compared to the free space but based on the -6dB reflection coefficient desired WLAN and HiperLAN operating bands are covered. The pattern diversity of the PIFA helps to mitigate the multipath fading effect. The calculated values of SPLSR over human head phantom in found well below 0.3 which satisfies the FCC standard.

Thereafter, a miniaturized triple-band MIMO/Diversity antenna is proposed. The main radiating element of the proposed triple-band MIMO/Diversity antenna is constructed by a meandered line and a folded patch with two vertical parasitic strips so that it makes compact ($9 \times 8.8 \times 5.4$ mm^3) to fit into the mobile phones. The meander line structure is introduced on the upper plate of the Main arm to increase the electrical length that decreases the resonant frequency from 3.6 GHz to 2.5 GHz. In order to achieve multi-band operation by this antenna, two vertical side arms acting as parasitic elements are added. With Side arm 1, the antenna resonates at 2.5 GHz (WLAN band) as well as 5.2 GHz (HiperLAN band). To additionally achieve WiMAX frequency band, vertical Side arm 2 (corresponding to $\lambda/4$ at 3.4 GHz) is added and hence the proposed antenna resonates at 2.5 GHz, 3.4 GHz, and 5.4 GHz corresponding to the WLAN, WiMAX, and HiperLAN bands, respectively. By properly placing of the MIMO antenna elements at each corners of mobile circuit board, achieved isolation between each antenna elements are below -10dB. However, when implement this MIMO antenna elements in the actual mobile platform there may be a chance to degrade the isolation performance. In view of this, the folded shorting strip is used to enhance the isolation between MIMO antenna elements. The placement of folded shorting strip is at the edge of the substrate so that other mobile components are placed easily between MIMO antenna elements. Finally antenna is fabricated using 0.2mm thick copper sheet. The fabricated prototype is tested/measured using network analyser and found application platform over the IEEE 802.11b/g (2.42–2.48 GHz), WiMAX (3.25–3.5 GHz), and IEEE 802.11a (5.15–5.83 GHz) bands for mobile handsets. The simulated and measured radiation patterns are point to complimentary in space region which shows the pattern diversity of MIMO antenna and helps to mitigate multipath fading effect. In the actual scenario of the mobile environment, proposed antenna satisfies all the diversity performances. The calculated values of the SPLSR for the multi antenna system found well within standard limit.

Technology moves towards next generation wireless communication. In mobile communication, Long Term Evolution (LTE) MIMO systems have drawn a great attention. Therefore, a compact quad-band PIFA structure is proposed which operates over GPS L1 (1.565-1.585 GHz), Bluetooth/ Wi-Fi (2.4-2.484 GHz), LTE2500 (2.5-2.57 GHz for uplink, 2.62-2.69 GHz for downlink), WiMAX (3.3-3.4 GHz), and HiperLAN1 (5.15-5.35 GHz) bands which suitable for next generation mobile handset applications. In the quad-band MIMO antenna each elements are referred as Antenna 1 and Antenna 2 which are mirror image of each other, and are mounted at the top corners of mobile circuit board. Each PIFA elements of MIMO antenna are folded at the edge of the substrate to make compact structure. The folded patch gives the desired resonance at 1.575 GHz along with the one higher order mode centred at 3.1 GHz. Another higher order mode is present at 5.1 GHz, but with a VSWR not better than 3:1. Further, to improve its matching, a rectangular quarter wavelength slot of dimension 12.3 × 1 mm^2 is cut at the top surface of the rectangular PIFA. Now, further, the vertical strip provides the inductive effect and is connected to the edge of the lower patch of the main radiator. The overall size of each antenna element is 25 × 10 mm^2. After addition of the vertical strip and optimization of shape parameters of the PIFA element, the proposed antenna shows quad-band nature which supports GPS L1, Bluetooth/ Wi-Fi, WiMAX, and HiperLAN frequency bands. The measured results found in good agreement with simulated results. The radiation and diversity performances of the quad band PIFA are calculated and found suitable for MIMO applications. The robustness of the proposed antenna is checked by placing the MIMO antenna in mobile environment and near to the users' body. The positions of the antenna are chosen at top as well as bottom positions of the mobile circuit board for the study. The top located quad-band MIMO antenna configuration gives better performances than bottom located antennas.

Further, trend of mobile phone moves towards slimness, hence, a compact, printed planar monopole antenna is designed with MIMO configuration for LTE700 and WWAN frequency bands. The single PMA element of MIMO configuration is constructed by two capacitively coupled-fed meandered and shorted loop antennas which are closely mounted with the separation of 12 mm (0.03λ at 762 MHz). The closely-spaced PMA provides less that -10dB isolation at the higher frequency side. So it is required to improve the isolation between PMAs. In view of this, T-shaped protruded ground plane is used between MIMO antenna elements to enhance the isolation between elements. By the use of simple T-shaped protruded ground plane isolation between antenna elements is enhanced and obtained less that -10 dB over the operating frequency bands. The dimensions of the PMA and protruded ground plane are optimized by simulation software (Ansoft's HFSS) and optimized result is measured and found in good agreement with simulated results. The PMA is also implemented with actual mobile environment by considering the major metallic components of mobile handset such as LCD, battery, microphone, buttons, camera, speaker, and connectors. From obtained *S*-parameters in mobile environment, it is corroborated that proposed PMA operates over LTE700, GSM1700, GMS1800, UMTS, Wi-Fi, Bluetooth, LTE2300, and LTE2500 bands for the 2G/3G/4G mobile terminals. The radiation patterns of the PMA shows pattern diversity which is used to mitigate the multipath fading effect. All the diversity parameters are calculated and found within range of the defined limit. The commonly used configurations namely, Talk mode, Data mode, and Read mode are considered. The antenna are kept at top and bottom position of the mobile and placed near the user's body. Further all the diversity parameters are investigated which satisfies the diversity criterion of the proposed MIMO antenna system. The standard limit of SPLSR i.e. 0.3 is satisfied by the proposed planar monopole multi antenna system for top as well as bottom position.

As for the future work, there are still several important directions in this area. The lower operating frequency band may be widening by using parasitic elements. Further, the size of MAS may be reduced by the use of lumped components. The MIMO antenna systems may be applied to some other technology such as body centric communication and RFID.