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SUMMARY AND CONCLUSION

Thin mobile phones are recently becoming more attractive for mobile users. For applications in the thin mobile phones, it is required that the embedded internal antenna should be of thin profile. In addition, multiband/wideband operation covering LTE700/GSM800/900/GPSL1/GSM1800/1900/UMTS/ IMT2100/Wi-Fi/LTE2300/2500, and WiMAX frequency bands is also must for the promising internal antennas. In view of the above an endeavour has been made in this direction. Consequently, both simulation and experimental investigations on planar monopole antennas for slim mobile handset applications are carried out. Although the various aspects of the investigations are discussed widely in separate chapters for the sake of convenience, the major findings of the entire work are summarized in this chapter.

In the beginning the introduction on multiband/wideband planar monopole antennas is presented thereafter, various internal antennas used in mobile handset are discussed in details followed by brief historical review on the topic.

The investigation on compact multiband planar monopole antenna for slim mobile handset applications is presented. This antenna consists of two resonating branches, one is C-shaped and other is meandered line connected with L-strip. The electrical length of the meandered line branch is approximated as $3\lambda/8$ at the lowest resonant frequency and C-shaped branch is resonant approximated as $\lambda/4$ responsible for the higher frequency bands. The design antenna operates over 0.885GHz–0.962 GHz (lower) and 1.69GHz–3.8GHz (higher) frequency bands with −6 dB impedance bandwidth. The antenna covers GSM900, GSM1800, GSM1900, UMTS, IMT2100, WLAN, WiMAX along with most of the higher LTE bands of modern mobile phone applications. From the simulated study conducted on planar monopole antenna, it is found that, with the increase of length of horizontal strip of C-shaped branch, resonant frequency around 2.5 GHz decreases rapidly whereas it is almost unaffected around 3.5 GHz and 1.8 GHz. Also, slightly increase on the lower edge frequency of the higher frequency band is observed. The impedance matching around 3 GHz and 2.7 GHz reduces while impedance matching around 2.0 GHz gets improved. Since the length of quarter wavelength C-shaped strip is responsible for resonating mode around 2.4 GHz and 3 GHz, shifting of resonant frequency around 2.5 GHz towards lower frequency takes place while mismatching occurs around 3.4 GHz.

The second arm of main radiator is meandered strip which is responsible for the lower operating frequency band. The meandered strip consists of horizontal and vertical strip. With the increase of length of horizontal strip, the resonant frequency around GSM900, 2.5 GHz, and 3.5 GHz decreases while the resonant frequency around 1.8 GHz is unaffected. This 1.8 GHz resonant frequency is fundamental resonating mode at $\lambda/4$ length of C-shaped strip, hence it is unaffected due to change in the length of meandered section. Further, with the increase in the vertical length of the meandered strip, the gap between the meandered line sections with L-strip line decreases which results in shifting of the resonant modes towards lower frequency side while improvement in impedance matching is observed at higher frequency side. In addition to the length of the strips, widths of the strips are also responsible to tune the resonating frequency. With the increase of widths of the C-shaped strip, significant effect is observed at higher frequency side with improved impedance matching. The width of meandered line strip also helps in impedance matching not only at lower operating frequency but also at lower operating frequency.

Further widened the GSM 900 band to achieve the GSM 850 band along with GSM900/GSM1800/GSM1900/UMTS/IMT2100/WLAN/LTE2500/WiMAX frequency bands along with all the higher LTE (Long Term Evolution) frequency bands by maintaining the same size of the antenna as well as mobile circuit board which was considered in the previously discussed antenna, shorted planar monopole antenna is studied. The shorted planar monopole antenna consists of three branch namely C-shaped branch, meandered line branch, and shorted arm. The C-shaped branch and meandered line branch consists of horizontal and vertical strips where as shorted arm consists of horizontal branch. It is noticed that the C-shaped branch is responsible for higher frequency and meandered line branch responsible for lower operating frequency. With the increase of length horizontal strip of C-shaped branch resonant frequency decreases rapidly around 2.0 GHz and 2.4 GHz whereas it is almost unaffected around GSM 850/900 band. The impedance bandwidth ($S_{11} \leq -6$ dB) of higher frequency does not get affected significantly, but the impedance matching around 3.0 GHz and 2.7 GHz reduces while impedance matching about 2.0 GHz gets improved. Since the length of quarter wavelength C-shaped strip is responsible for resonating mode around 2.0 GHz, shifting of resonant frequency around 2.4 GHz toward lower frequency takes place while mismatch occurs around 3.5 GHz. Further, with the variation of width of the C-shaped branch, the impedance bandwidth insignificantly affected at over all frequency band while more prominent matching is observed around 1.9 GHz, 2.4 GHz, and 3.5 GHz. It is interestingly noted that the width of the horizontal strip of C-shaped branch affects the higher frequency band significantly as it is directly fed by feed line and with increase of horizontal strip impedance matching improves significantly at higher frequency side. Since these width are related to C-shaped branch therefore lower frequency band is not affected. In addition to the above parameters, the variations of feed position and length of shorting strip, both the lower and higher frequency bands are affected significantly. With the increase of position and shorting strip length the impedance matching toward higher frequency side improves significantly, while the lower frequency band shifted toward lower side.

Thin profile wideband printed monopole antenna is investigated to cover LTE700/GSM850/900, GPSL1/GSM1800/1900, UMTS/IMT2100/Wi-Fi/ LTE 2300/2500, and WiMAX frequency bands based on –6 dB reflection coefficients. The proposed planar antenna utilizes the concept of couple fed and back side parasitic elements to widen the operating frequency band. The critical shape parameters of the antenna are investigated. It is observed that the variation of separation between driven and coupled elements affect all over the frequency band. When gap is more, the impedance matching about all the frequency bands with some significant mismatch about GSM800 band whereas for minimum gap impedance matching gets deteriorated significantly towards lower frequency bands as well as WiMAX bands. Further, with the variation of the position of shorting strip connecting position at the coupled strip the impedance matching significantly affected about GSM800 band and WiMAX bands. With the decrease of position, the impedance matching improves towards lower frequency side while deteriorated at higher frequency side. In addition to this, variation in the position of the meandered parasitic element is carried out and observed that it plays significant role on the impedance matching. It is observed that when the meandered line shifts from the top position impedance matching gets disturbed while at the extreme top position wideband characteristics is observed. When the gap between the horizontal arm of the meandered line increases the matching towards higher frequency decreases with some improvements towards lower frequency side.

Further investigations of all the three planar monopole antennas are carried out in the presence of the user proximity. The effect of user proximity is analyzed on the performance parameters of the planar monopole antennas. There are three commonly used configurations i.e. talk mode, data mode, read mode are considered for study point of view by placing the antenna at top and bottom position of the mobile circuit board. The *S*-parameter, radiation performances, SAR calculation, and TRP calculation are studied. From the *S*-parameter of all three antennas, it is observed that in most of the cases planar monopole antennas covered the desired operating band but in some of the cases the antenna shape parameters need to be detuned to achieve the desired operating bands.

The investigations of peak realized gain, total antenna efficiency for top as well as bottom located antenna elements are calculated and found that the bottom located antenna elements show better performances. The calculated values of SAR for all three antennas are well below the standard limit i.e. satisfies the European standard (<2W/kg over 10 g of tissue) and American Standard (<1.6W/kg over 1 g of tissue). The TRP is also calculated for the three antennas to check the operation of all three antennas in the presence of user's body and it is observed that it is more than required limit for various configurations.

In order to miniaturization of the size of antenna element still there is scope for future research work. The size reduction with bandwidth enhancement of the planar monopole antenna can be done by using metamaterial and artificially developed dielectric materials for substrate like ceramic material.