Frequency reconfigurable LTE antenna with u shaped open end for portable wireless devices

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Abstract. In this paper, a frequency tuning method for an U-shaped slot antenna for long term evaluation (LTE) wireless communication devices is presented and the performance of the antenna (return loss, total and radiation efficiencies...etc) is reported. The lower operating frequency of the antenna (700 - 960 MHz) is switched with different inductor loadings from 110 nH to 30 nH. The inductor component loads the U-slot antenna and thus enables to tune the frequency of low band (700 - 960 MHz). Higher bands (1710 - 2700 MHz) of the antenna remain unchanged with different inductor loadings. The impact of the inductor position is also investigated and the results are reported. The antenna presented in the paper is comparable with that of Cho-Kang Hsu's publication. However, in Chos publication, only one low band is covered. In our design, all of existing commercial LTE frequency bands (Band 17 - Band 7) used in typical mobile devices are covered by the proposed antenna.

Keywords—Long Term Evaluation;Slot Antennas; Inductor loading;

1. Introduction

In today's world there is an ever increasing demand for communication systems and antennas on hand held devices are needed to support numerous bands of 4G and 5G. Small size, simplicity, high bandwidth and compatibility to the rest of the RF front-end are desirable factors of an antenna. The metal casings are need of the day to produce hand held smart devices having low volume, thin and light weight. But due to the addition of the metal casings the bandwidth and radiation efficiency of conventional antennas in handheld devices tend to decrease when the antenna is in the proximity of metal casings. Even Without metal casing the normal planar monopole and planar inverted-F antennas are the best examples which don't provide sufficient bandwidth to use in hand held devices. Different types of slot antennas provide higher bandwidth and radiation efficiency in the presence of metal casing. Therefore, slot antennas become attractive for hand held devices with metal casings. A different type of slot antennaestructures, including circular [1]-[3], triangles [4], [5] and fractal shape [6], have been proposed to achieve a wide impedance bandwidth. A wide slot supportmany resonance modes, and the formation of a wider bandwidth by combining twoadjacent resonance modes is explained in [7]. However, in the antenna design, the area required in the citations from [1] to [7] requires large area for the slot which is a major constraint in the small hand held devices. So the usages of the antennas are limited in small area
applications. Various antenna design techniques have been proposed and implemented to decrease the total size of the multiband slot antennas. Quarter-wavelength open slots are designed in [8] and [9] to attain a compact size. In [10] and [11], several independent slots which operate in half wavelength are used to generate multiple bandwidths. A small size and low profile antenna is achieved in [12] using planar inverted-F antenna (PIFA) combined with a slot in the ground plane. [13] and [15] depicts the method of combining slotted ground plane with Multi-strip monopole antenna to generate a wider bandwidth. In [16], a tunable dual-band slot antenna was designed by tuning the capacitance of a varactor across the slot.

The operating bands of the antenna can be increased from single band to multiple bands with the above different miniaturization and bandwidth enhancement methods. However, attaining multi band slot

![Figure 1. Schematic layout of the proposed antenna with U-shaped open-end loaded with inductor. (Dimensions in mm).](image)

antennas within a compact structure is still a challenge. Different methods are utilizing to generate multi band slot antennas with a compact structure. This paper proposes a compact multi-band antenna composed with a straight coupled-fed microstrip line, a reduced open end slot and a U-shaped slot, to generate four resonance modes, including two monopole and two slot modes and the operating frequency of the antenna is tuned with a

Various inductor components [17],[18]. The benefits of the proposed structure is to obtain the wide bandwidth (1700 - 4200 MHz) on the high frequency band and in the lower frequency band (690 - 960 MHz) respectively to cover all the commercial LTE bands. This result is better than the bandwidth of reference papers [8]-[19] (1700 - 2800 MHz) and is better than the bandwidth of reference paper (690 - 742 MHz). The design process and all the simulated results are presented and discussed. All the simulations in this study are performed using computer simulation technology.

2. Antenna design

2.1. Antenna Configuration

Figure 1 depicts the geometry of the proposed frequency reconfigurable antenna with U-shaped open-end loaded with inductor. The antenna was simulated on FR4 ($\varepsilon_r = 4.43$) with a thickness $t = 0.6$ mm and 120 mm x 70 mm with copper on one side. The dimensions of the proposed antenna are shown in the Figure 1.

A metal strip of dimension 31 mm x 2 mm was inserted, leaving a slot of width on the upper and lower edges of the aperture, to construct a U-shaped slot. At one end of the U-shaped slot, a tapered open-end structure was connected. A 50 ohm microstrip line of width 1.1 mm was printed on the opposite side of the ground plane to form a coupled feed.
2.2. Antenna Working Principle

The path of the open-end slot of $l_1 + 2 \times l_2 + l_3 + l_4$ which is a monopole slot, which offered the longest resonant path to generate a quarter-wavelength mode at low frequency. Two strips $l_4$, $l_5$, were excited using the coupled feed line. The open end microstrip line of length $l_f$ and $l_f + l_3/2$ provide the effective coupling capacitances to produce the energy coupling on the $l_4$ and $l_5$, respectively, to generate two quarter-wavelength monopole modes at high frequency. Along with this, one wavelength slot resonance on the high frequency was generated by the rectangular looped path which is formed by the area between the U-shaped slot of length $2 \times l_2 + l_3$ and the microstrip line $l_3$ truncated by the slot lines. Four resonant modes were generated using the proposed structure. The relative resonant frequency computation for the four modes is listed as follows.

\[
\begin{align*}
  f_{r1} & \approx \frac{c}{4(l_1 + 2 \times l_2 + l_3 + \frac{1}{2}l_4)} \\
  f_{r2} & \approx \frac{c}{4 \times T \times l_5} \\
  f_{r3} & \approx \frac{c}{4 \times l_4} \\
  f_{r4} & \approx \frac{c}{2 \times (l_5 + l_1)}
\end{align*}
\]

The resonant behavior is further explained with the aid of the currents. Fig. 2(a) shows the surface current distribution on the monopole slot mode which is resonated at 720 MHz. Note that the wider the tapered open-end slot is, the shorter the effective slot length is. Here almost the entire induced current concentrates in the region of the tapered slot of a length. Fig. 2(b) shows the current distribution in the right strip, which has dimensions of $l_5 \times 7$ mm which shows the resonance path at 1.76 GHz, similar to a monopole antenna in its fundamental mode. The resonant frequency and bandwidth is reduced here, since the strip was closely surrounded by the ground, which is incurring a strong capacitive effect. The correlative parameter in $T$ was approximately 1.36 in value. Fig. 2(c) shows the distribution of the current on the left strip, which had approximate dimensions of $l_4 \times l_f/2$. This path is resonated at 2.4 GHz, similar to a monopole antenna in its fundamental mode. Fig. 2(d) shows the current distribution in the area between the U-shaped slot and the microstrip line truncated by the slot lines. The microstrip feed line which in turn provided two virtual shorts to form a path that resonates at 3.5 GHz. Here the current flows around the U-shaped slot which was indicated in the figure which generates an wavelength slot mode.

| Dimension | Length |
|-----------|--------|
| $l_1$     | 2      |
| $l_2$     | 33     |
| $l_3$     | 7      |
| $l_4$     | 30     |
| $l_5$     | 31     |
| $l_6$     | 5      |
| $T$       | 0.6    |
| $W$       | 70     |
| $L$       | 120    |

Table 1. Dimensions of the proposed antenna

3. Switch position parametric study

The inductor switch placement in the structure plays an important role here. The position of the switch is shown in the Figure 3.
Figure 2. Surface current of the proposed antenna at 110 nH loading. a) 700 MHz. b) 1800 MHz. c) 2500 MHz.

Figure 3. Schematic diagram showing the switch position.

Figure 4. Simulated return loss of the antenna with different inductor loadings.

4. Results

The switch 0 mm position indicates it is near to the feed position. It is gradually moved in X axis as shown in figure. In the low band the frequency resonance is occurred at 0.75 GHz for a switch position of 28 mm distance and 0.91 GHz at a position of 0 mm distance from the feed point. Similarly in the mid band range the frequency resonance is obtained at 1.73 GHz at a location of 0 mm distance and 1.94 GHz at a position of 28 mm distance from the feed point. In the high frequency band i.e over 2.3 GHz frequencies, the impact of the switch position on the resonance frequency is almost negligible.

4. Results

Figure 4 shows the simulated return loss of the antenna for different inductor loadings. For antenna loadings of 110 nH, 70 nH, 40 nH and 30 nH, the operational frequency of the low band tunes from LTE band 17, 13, 20, 5 and 8, respectively (LTE band frequencies can be found [21]).

The operational bandwidth of the antenna increases with decrease in inductor loadings. The antenna low band from 690-742 MHz frequency is increased to 690-960 MHz with different inductive loadings. For an inductive loading of 110 nH yields a low frequency value of 690 MHz and 30 nH
inductive loading gives a frequency value of around 960 MHz. To cover a wide frequency range, the inductive loading values have to gradually vary from a higher value of 110 nH to a lower value of 30 nH. This result is better than the band width of the [20]. High band of the antenna (1700 - 2700 MHz) almost remain unchanged for different inductor loadings. The inductor tuning is done by using a SP4T switch IC. Figure 5 shows the return loss variation based on the switch position for 30 nH. When the switch is positioned at 0 mm, the resonant frequency tunes around 0.91 GHz and when the switch is positioned in 28 mm the resonant frequency tunes around 0.75 GHz in the low band. In the high band, the impact of the switch position on the resonant is negligible.

Figure 6 depicts the total efficiency in dB of the antenna for different inductor loadings. Antennacovers lower frequency bands with a total efficiency of -4 dB and mid and high frequencies with an efficiency of -3 dB. Figure 7 presents the simulated gain of the proposed antenna for inductor loading. The gain of the antenna in the low band is a lesser value where as in the high band it is higher. The Figure 7 shows the gradual increment in gain for the increase in the frequency band.

Figure 5. Return loss variation based on switch position for 30 nH. a) Low band. b) Mid & high band

The simulated radiation pattern of the proposed antenna in low and high bands respectively for an inductor loading of 110 nH is shown in the Figure 8. As the frequency is increased, the directional property of the antenna is gradually increased. Figure 9 depicts the photograph of the antenna fabricated. Figure 10 depicts the comparison results of the simulated and measured return loss of the proposed antenna for 110 nH and 30 nH inductor loadings. In the low band, the return loss of the measured and the simulated results of the antenna are correlated very well. However in the mid and high bands there is a 50
MHz discrepancy between simulated and measured return loss. This can be attributed to the fabrication tolerances of the antenna.

![Simulated total efficiencies of the antenna with different inductor loadings.](image1)

Figure 6. Simulated total efficiencies of the antenna with different inductor loadings.

![Simulated Gain of the proposed antenna for different values of inductor loading.](image2)

Figure 7. Simulated Gain of the proposed antenna for different values of inductor loading.

5. Conclusions and discussions

In this paper a frequency reconfigurable open ended U slot antenna is presented and discussed. Here antenna covers all of the commercial LTE frequency bands. The frequency tuning in the low band is realized by switching different inductor loadings. The detailed design considerations of the antenna are described and the simulated and measurement results were analyzed. The experimental results show the frequency tuning in the low band while the mid and high bands remain unchanged. In future, this research work can be extended by incorporating multiple input and multiple output antenna (MIMO) in order to achieve higher data rates. Further, the effect of the user on antenna performance can be evaluated.
Figure 8. Simulated radiation pattern of the proposed antenna. a) Low b) Mid c) High band

Figure 9. Photograph of the fabricated antenna a) Topside  b) Bottom side
Figure 10. Simulated and measured return loss of the proposed antenna for 110 nH and 30 nH

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7. References

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