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Design and Parametric Analysis of Pentaband Meander Line Antenna for Mobile Handset Applications

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Abstract**—**Wireless communication technology is rapidly changing with recent developments in portable devices and communication protocols. This has generated demand for more advanced and compact antenna structures and therefore, proposed work focuses on Meander Line Antenna (MLA) design. Here, Pentaband MLA is designed on a FR4 substrate (85 mm x 40 mm) with dielectric constant (ϵr) 4.4, loss tangent (tan δ) 0.018 and height 1.6 mm with coplanar feed and open stub structure. It can be operated in LTE (0.670 GHz-0.696 GHz) GPS (1.564 GHz-1.579 GHz), WCDMA (1.920 GHz-2.135 GHz), LTE UL frequency band 23 (2-2.020 GHz) and 5G (3.10 GHz-3.550 GHz) application bands. Also, it gives good performance in terms of Return Loss (RL) which is < -10 dB, impedance bandwidth with maximum Bandwidth (BW) up to 0.21 GHz and realized gains with maximum gain up to 3.28 dBi. Antenna is simulated with open stub and without open stub structures to see the effect on impedance BW coverage. In addition to this, it is checked with human hand and head phantoms to assure that it falls within specified Specific Absorption Rate (SAR) limits.

Keywords**—**Coplanar feed, L shaped ground, MLA, phantom, SAR, stub.

I. Introduction

TODAY'S wireless mobile communication requires a mobile device with many features like high data rates, low power consumption, high efficiency, high linearity multiband characteristics. So, there is a need of simple, efficient, cost effective, multiband, low-profile antennas [3] which can be fulfilled by using concept of meander line geometries. Amongst these, BW can be enhanced by using the techniques like loading of the surface of the printed element with slots [10], texturing of narrow or wide slits at the boundary of the micro strip patch [6], utilization of additional parasitic patches i.e. extra microstrip resonators and size can be reduced by using high permittivity substrates, shorting pins [10] and meandering the patch. Again, to deal with the electromagnetic absorption by human body, internal antennas are being used which include Planar Inverted-F antennas, monopoles, fractal and meander antennas. By studying and taking into consideration advantages and disadvantages of all above mentioned techniques, best are chosen for this work i.e. slot loading and meandering. Antenna miniaturization is required particularly for low frequency band systems where the size of the antenna is very large. Meandering which is folded monopole microstrip antenna can greatly reduce the size by increasing the current path specifically at lower resonant frequencies that too retaining the properties of monopoles and these are electrically small antennas [12] which are used to overcome the several performance issues such as low gain, narrow BW and high Voltage Standing Wave Ratio (VSWR).

Many multiband antenna designs as well as designs for different applications are put forth by using meander geometry. In [1], meander line technique is used for the size reduction of Quadrifilar Helix Antenna. Although efficiency is lower, 53% size reduction and considerable increase in BW i.e. 100 MHz is achieved. Comparison of the performance properties of Hilbert curve fractal and Meander line monopole antenna is studied in [2], occupying the same plane area and same total wire length where concluding remarks say, meander geometry can exhibit significantly lower resonant frequency. Mathematical designing of MLA is given in [6] as well as it is shown that, for desired frequency range, empirical relationship between dimension and various parameters can be evaluated by theoretical calculations. In [8], properties of MLA, Meander Line design along with the structure for ISM band 2.5 GHz are mentioned. For single frequency band of UHF having f_r 878 MHz, geometry is proposed in [16], with the use of slot loading and meander line concept and so, 70% size reduction with the conventional monopole antenna is achieved. Though radiation pattern is omni-directional with the efficiency of 41%, the gain is negative i.e. -1.18 dBi. References [4], [5] and [9] are the antenna designs on a FR4 substrate for dual/tri bands 2.4/5/5.8 GHz with the simple microstrip and adaptive feeding techniques but are only specific for the application of WLAN. Meander antenna covering dual bands of GSM 900/1800 and UMTS is designed in [13] for energy harvesting applications. This antenna is compared with reference dipole and both are tested with RF energy harvesting kit. A meandered rectangular monopole antenna for Quad-band applications is given in [12] which covers CDMA 2.1 GHz, WiMAX 3.53 GHz, wireless avionics 4.3 GHz, and the upper UWB (5-11.6 GHz).

Dependence of RL with varying slot lengths is also studied. Maximum impedance BW of 70 MHz is observed with omni-directional radiation pattern but again the gain values are negative for lower three frequency bands. Antenna for more than four bands is designed in [14] for portable communication devices based on meandered line loops and T

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shaped ground plane. Along with this parametric analysis is done. It is suitable for JCDMA, UHF RFID, GSM 900, GPS, KPCS, DCS, IMT-2000, WiMAX, WiFi, and Bluetooth with operational BW of 550 MHz to 3.85 GHz, peak gain and efficiency of 5.5 dBi and 90.1%. Work based on designing of antenna for mobile handset applications is presented in [7]-[11] and [15]. In these, [11] consists of design for dual bands of WLAN and Fixed WIMAX application by using two techniques i.e. loading of high permittivity material in substrate of an antenna and using shorting pin in meander slot antenna. It has low impedance BW and gain values are positive, 2.24 and 3.35 dBi; but design is only able to cover 2 frequency bands. In addition to this, high permittivity and greater height for the substrate are used. In [7], penta-band geometry is proposed for CDMA, GSM, DCS, PCS, WCDMA with the good performance characteristics as well as antenna structure with open stub is simulated and tested with human phantoms. However, feeding technique used here is perpendicular feed which is difficult to design in terms of alignment of angle. In [15], antenna is designed for LTE/WLAN/WIMAX with the use of folded loop line, rectangular patch inserting meandered slit and L-shaped ground branch which is closely coupled to the feed line structure, taking into consideration dimensions of mobile phone PCB as well but is not tested for the SAR values.

This work is focused on designing pentaband meander antenna on a FR4 substrate with simple coplanar feed mechanism by considering similar dimensions as that of mobile phone PCB. Parametric analysis is done based on stub length and width, stub radius, and L shaped ground dimensions. Also, the geometries with and without stub are simulated as well as final design is checked for the SAR values.

Organization of the paper is such that Section II is antenna structure and design, Section III is concept behind meandering, Section IV is experimental results and discussion, Section V is conclusion.

II. Antenna Structure and Design

Antenna is simulated on a CadFeko Electromagnetic Solver with FR4 substrate dimensions as 85 mm x 40 mm x 1.6 mm having ∈r 4.4 and tan δ 0.018. Main part of design is built on a 24 mm x 40 mm area and remaining portion is ground.

Figs. 1 (a) and (b) show overall antenna geometry and dimensions with open stub where all dimensions are in millimeter. This is a complete planar structure. By selecting appropriate position of stub and feed line, antenna is resonated at five application frequencies. Stub is used to match load impedance to the transmission line characteristic impedance. To cancel the reactive part of the presented impedance, accordingly length of the stub is chosen. Each resonant frequency is having its own electrical length depending upon the current distribution and equivalent radiating surface and non-uniform meander structure causes surface current distribution to be non-uniform. Making the ground plane large helps improve potential BW.

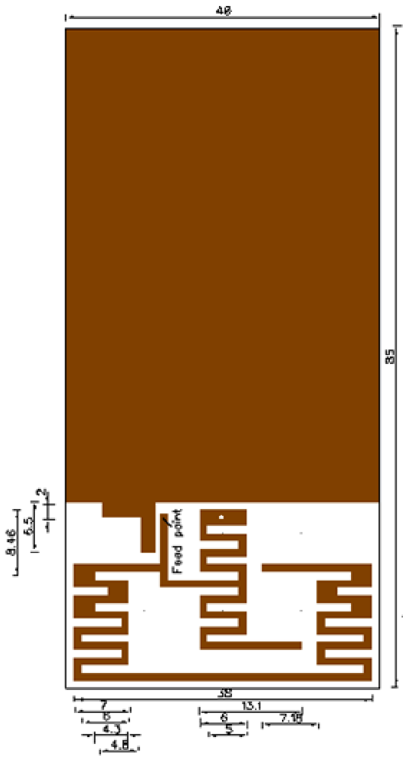


Fig. 1 (a) Antenna Top view (With Stub)

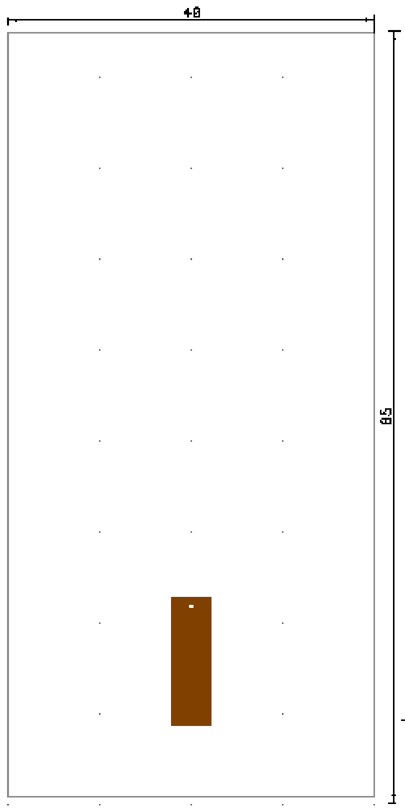


Fig. 1 (b) Bottom view

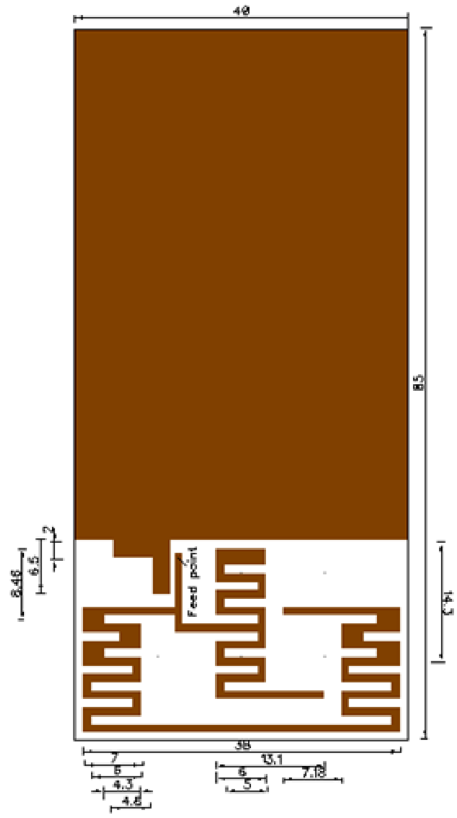


Fig. 1 (c) Antenna geometry without stub

III. Concept behind Meandering [8]

Fig. 2 shows equivalent model of MLA. It acts as resonant LC circuit. Horizontal and vertical segments act as inductor and capacitor respectively. Because of meandering, the path over which surface current flows increases. Effective capacitance and inductance increases due to increment of current path and this leads to decrease resonant frequency since $Fr = \frac{1}{\sqrt{2\pi LC}}$. So, for lower resonant frequency also, miniaturization is possible and radiations are mainly due to vertical segments because adjacent horizontal segments have opposite phase.

IV. Experimental Results and Discussion

A. Geometry Results with and without Stub

According to the design procedure explained above, antenna is simulated on an electromagnetic solver called CadFeko and the results obtained with and without open stub structures are shown in Fig. 3 (a).

If results are compared for both, it is clearly seen that more number of bands are getting with stub structure. However, without stub only two significant numbers of bands are obtained which are Digital Communication Systems (DCS 1.710 GHz-1.784 GHz) and Global System for Mobile Application (GSMA 2.5 GHz-2.690 GHz). This is because open stub structure is helpful in impedance matching and particularly at lower resonant frequency like 0.7 GHz where matching is really difficult, it is done by selecting appropriate length and width of bottom rectangular portion and stub radius. Since antenna design with open stub is more advantageous, we are purposely going forward with the discussion of same. Table I shows the band coverage and applications for the design with stub structure.

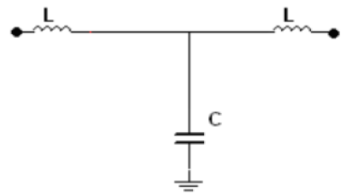


Fig. 2 Equivalent model

TABLE I
Application Bands Covered

Resonant Frequency (GHz)	Return Loss (dB)	Application Band and Its Corresponding BW Covered
0.681	-14.93	LTE (0.670-0.696)
1.5	-26.22	GPS (1.564-1.579)
2.045	-25.82	WCDMA (1.920-2.135) LTE band 23-UL frequency (2.000-2.020)
3.015	-29.68	5G (3.100-3.145)

It can be observed that mainly five application bands are covered with this antenna design. Fig. 3 (b) shows simulated current distributions for the proposed antenna.

It can be seen from the current distributions that total electrical length for the lower resonant frequency is much greater than other resonances. Lower and higher frequency bands are mainly occurred due to center (straight) meander section as well as folded meander loop whereas, middle bands are mainly due to center meander line. Depending upon the current distributions on L shape ground and open stub structure, RL varies. When current density or current concentration is more on stub, matching is really good. In the first case, there are more losses near stub structure. However, in second and third cases matching is good i.e. current is more concentrated on stub but there are significant losses on ground plane. Now, the forth case is somewhat similar to first with respect to losses ground plane but current density is more on stub than all the other three cases and hence RL value is quite low. Total electrical length for the lower resonant frequency is much greater than other resonances. It ranges between 0.3λ to 0.32λ for all frequencies which is 1.2 times of standard monopole length.

TABLE II
Efficiencies with and without Open Stub

Resonant Frequency (GHz)	With Stub Efficiencies (%)	Without Stub Efficiencies (%)
0.681	40 %	1.772 GHz - 50
1.5	82%	
2.01	79%	
2.045	80 %	2.833 GHz - 52
3.015	77 %	

Fig. 3 (c) shows the radiation patterns of the antenna structure. Patterns are almost omni directional except it gets slightly deteriorated for the upper frequency of operation. Maximum gain of up to 3.28 dBi is obtained at 2.045 GHz. Table II shows efficiency comparisons.

Looking at the efficiency values, performance of the antenna is improved by the use of open stub.

(__: With Stub, __: Without Stub)

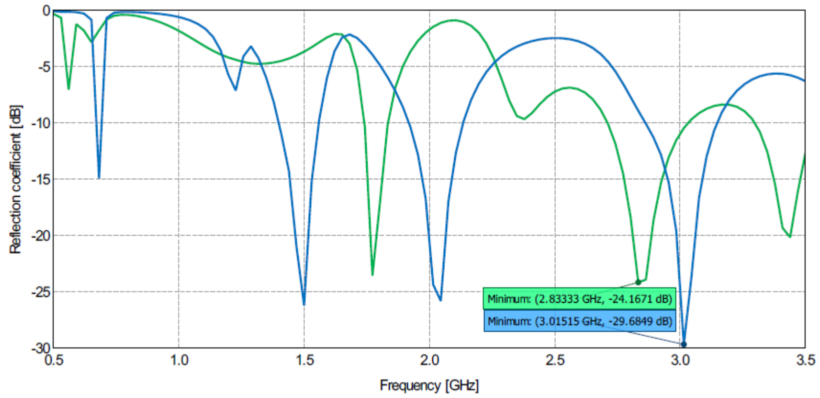


Fig. 3 (a) Reflection Coefficient Magnitude

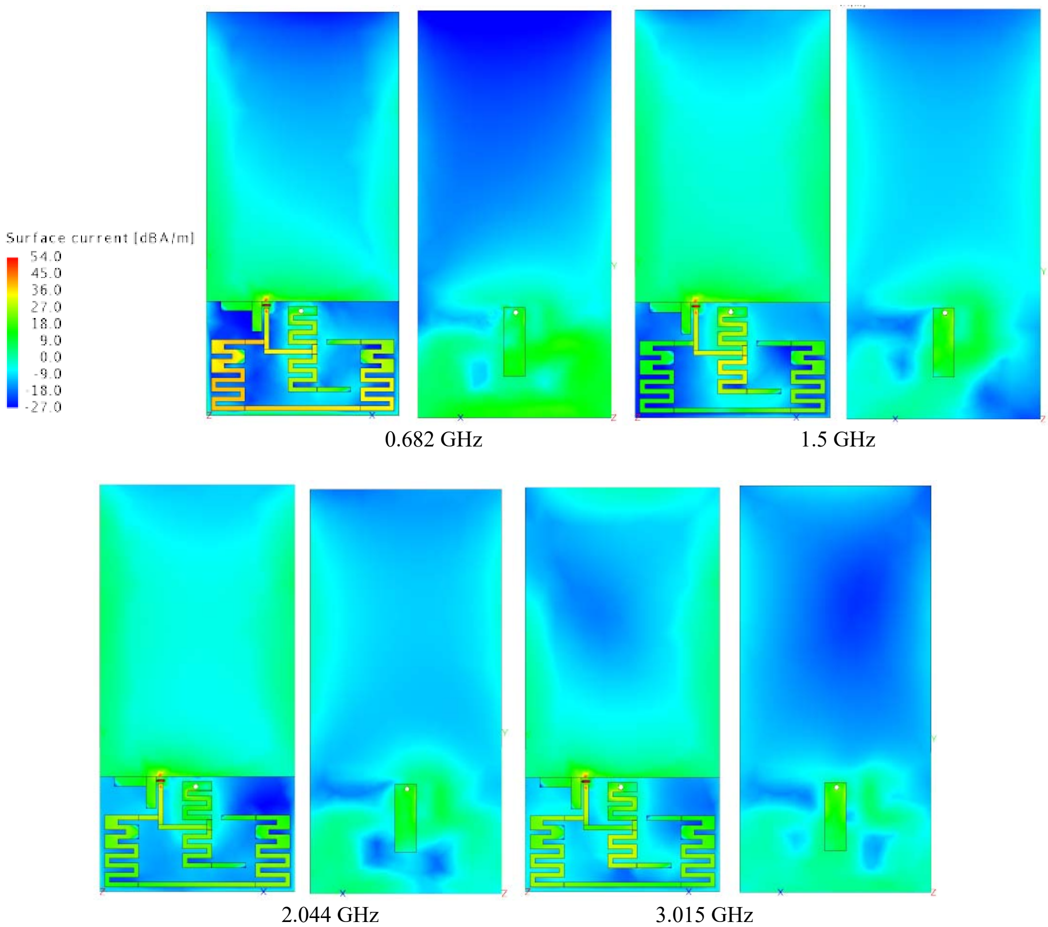
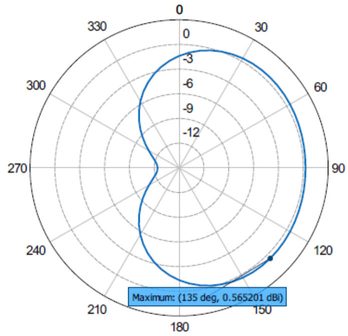
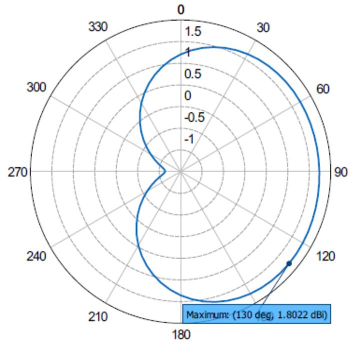


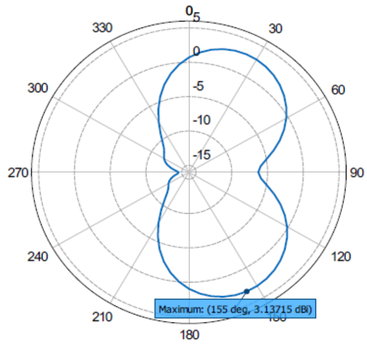
Fig. 3 (b) Current Distributions



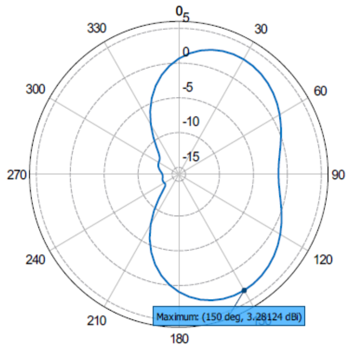
0.682 GHz



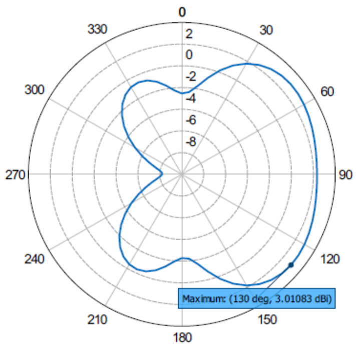
1.5 GHz



2.015 GHz



2.045 GHz



3.015 GHz

Fig. 3 (c) 2d radiation patterns

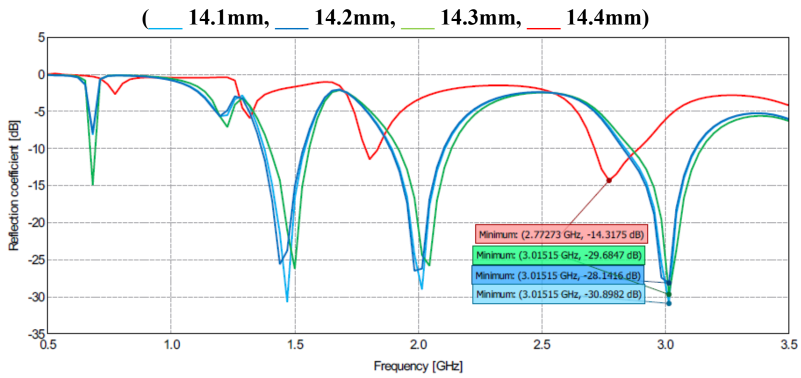


Fig. 4 (a) Variation of length of stub

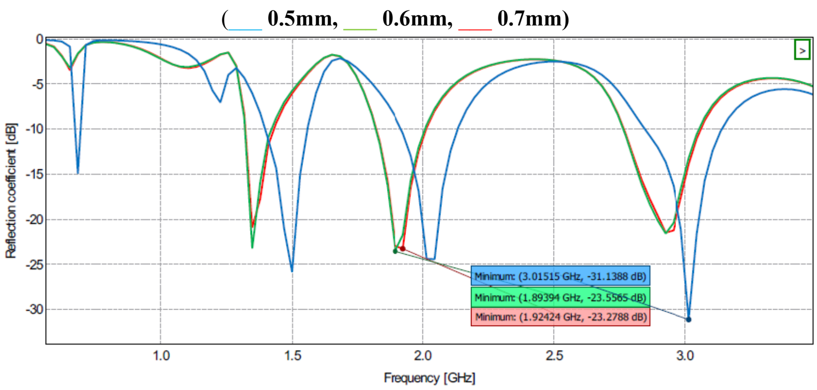


Fig. 4 (b) Variation of stub radius

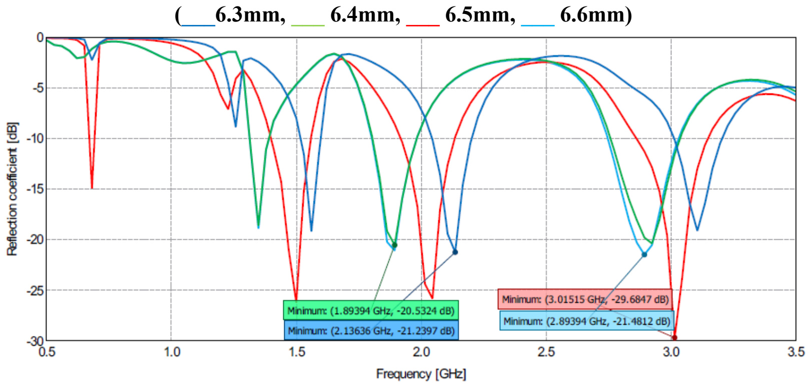


Fig. 4 (c) Variation of the length of vertical rectangle

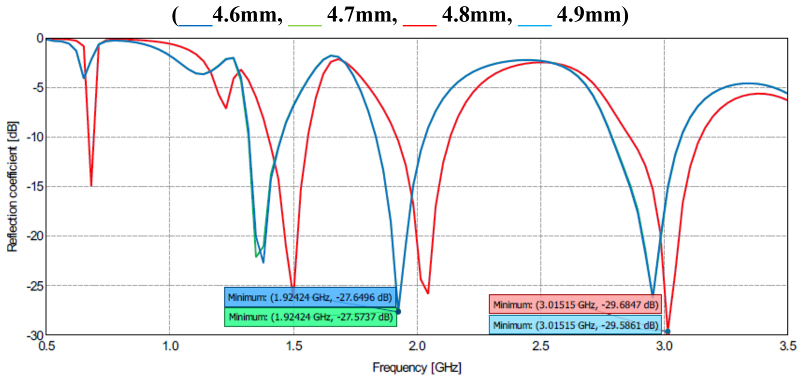


Fig. 4 (d) Variation of length of horizontal rectangle

B. Parametric Analysis

Parametric analysis is done to justify the antenna design and dimensions. Results are analyzed by varying the dimensions of stub and ground. Variation of length and width of bottom rectangular portion, radius of open stub, horizontal and vertical rectangles of L shaped ground have significant effects on results and hence these points are taken into consideration while designing the antenna.

1. Variation of the Length of Stub or Bottom Rectangular Portion

Fig. 4 (a) shows the reflection coefficient magnitude graph with different lengths of stub.

As seen from the comparison in Fig. 4 (a), when the stub length is 14.1 mm, very low RL values are obtained for all three frequency bands except 0.7 GHz. Similar is the case for 14.2 mm, only RL values are somewhat greater while for both of these cases lower frequency band of 0.7 GHz does not have proper impedance matching giving RL nearly equal to -7dB i.e. < -10 dB, which cannot be considered for the application. Worst is the case for 14.4 mm, because frequencies are shifted by much greater value to the left from actual application coverage and that too only one significant band is there whose RL can be taken into account. However, when the stub length is 14.3 mm there is a proper matching for all the frequency bands with RL < -10 dB.

2. Variation of Stub Radius

Fig. 4 (b) shows the reflection coefficient magnitude graph with different radius of stub.

With the increase in stub radius from 0.5 mm to 0.7 mm, RL increases but does not increase to the value as that of the case for stub lengths whereas situation is quite similar to that of the first for 0.7 GHz and also frequencies get shifted to left.

When stub length and radius are 14.3 mm and 0.5 mm, imaginary part of the impedance observed is very low i.e. 2.723. It shows that the inductive (reactive) impedance presented by antenna is effectively canceled by the stub and this is the reason behind correct matching.

3. Variation of the Length of Vertical Rectangle of L Shaped Ground

Fig. 4 (c) shows the reflection coefficient magnitude graph with different lengths of vertical rectangle. By observing this graph, keeping the length of vertical rectangle as 6.5 mm gives good results as that of the first two cases. Deviation from the actual dimension of 6.5 mm gives the results having shifted frequencies to left and right with higher RLs. Variation of this parameter has not only considerable effect on lower frequency band but also on two upper frequency bands.

4. Variation of the Length of Horizontal Rectangle of L Shaped Ground

Fig. 4 (d) shows the reflection coefficient magnitude graph with different lengths of horizontal rectangle.

Varying the length of horizontal rectangle does not change the RL value by greater magnitude but again for the 4.8 mm length only, good impedance matching for all the application bands is obtained. From all the above four cases, frequencies can be tuned to required application bands by selecting correct position and dimensions of parameters however the impedance matching for lower frequency band can only be achieved by the selection of exact dimensions of stub length, radius as well as the vertical rectangle of L shaped ground.

C. Antenna Geometry Tested with Human Phantoms

Antenna geometry is simulated with the human hand and head phantoms to see the effect of electromagnetic absorption by body. While simulating, the standard average dimensions of adult's hand and head are considered and ∈r and σ are taken as 25.7 and 1.32 respectively. Figs. 5 (a) and (b) show designs of antenna along with phantom models.

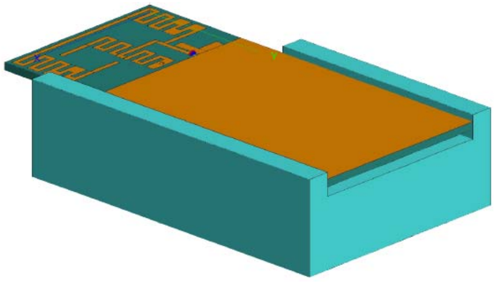


Fig. 5 (a) Antenna mounted on hand equivalent model

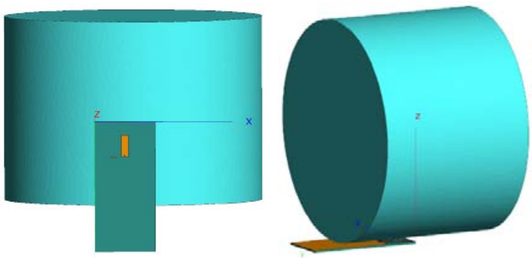


Fig. 5 (b) Antenna against head equivalent model

With phantoms, frequencies appeared to be shifted left by 0.1 to 0.2 GHz. Efficiency values with hand and head are compared and are observed less than free space because of electromagnetic losses in the human body.

Table III gives observed results with human phantoms.

TABLE III
EFFICIENCIES AND SAR VALUES WITH HUMAN HAND AND HEAD

Resonant Frequency (GHz)	With hand (%)	With head (%)	SAR values (W/kg) With Hand	SAR values (W/kg) With Head
0.681	20	14.85	1.6	1.6
1.5	22.11	17.19	1.6	1.6
2.01	31.46	26.97	1.55	1.53
2.045	32.10	28.42	1.56	1.50
3.015	36	29.56	1.57	1.52

Average SAR values over total domain are also verified and all are well below standard limit set by FCC i.e. 1.6 W/kg.

V. CONCLUSION

Proposed antenna is able to work in mainly five application bands of LTE 0.7 GHz, GPS 1.5 GHz, WCDMA and LTE 2 GHz and 5G 3 GHz. Antenna geometry with open stub has improved number of frequency bands covered and efficiency as compared to geometry without stub. Parametric analysis has shown the necessity in selecting the accurate dimensions for the design for desired applications. Along with this, antenna results with human phantoms having SAR less than specified limit assures that it can be used in mentioned wireless frequency bands for mobile handset application. Future scope of this work includes simultaneous tuning of antenna at multiple frequency bands of LTE. Though it will be more specific for LTE application, it will be able to cover wide frequency ranges.

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