Multiband Antenna using Excavated Coupling Element Approach Design for 4G LTE Band in Handheld Terminal

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***Abstract*—This paper proposes a novel antenna design for handheld terminal operating in LTE bands. The design involves two antennas ,one operating in a lower band of 700-960MHz while the other antenna incorporated in the same space operates in a higher frequency band of 1700-2700MHz.These two antennas are individually fed and excited demonstrating high port-to-port isolation. A unique type of excavated coupling element is used for lower band operation while the space availed by excavation is used to incorporate a high band antenna which is a simple monopole structure. The coupling element used for low band operation couples the radiation modes of chassis and requires a matching network comprising SMD components, monopole structure for high band operation on the other hand is a self resonant antenna structure modified with certain broad banding techniques. Careful placement of high band antenna and band stop behavior of matching network is used to establish port to port isolation. The simulated model is further used with approximated human head model to investigate specific absorption rate (SAR) characteristic of the design and the entire design process is carried out in full wave electromagnetic simulator Ansoft HFSS.**

***Keywords*— Handheld terminal; LTE-bands; Coupling element; SAR-specific absorption rate.**

I. INTRODUCTION

The handset industry has experienced a surge in the functionalities of hand held terminal during past decade which was previously intended only for voice communication .presently some of the diverse functionalities include video calling, web browsing, data transfer etc which form an antenna design perspective requires more number of frequency bands and such designs of antenna needs to be efficient involving lesser complications in design. The space allocated in handsets for incorporation of antenna however remains more or less unchanged but the need for more operational bandwidths is a challenge. The inception of smart phones did not change the situation and was more or less preserved since the printed circuit started to increase in width and length.

Today, a generic handset antenna should be able to cover:

- 700-787MHz (LTE Bands 12-13-17)
- 824-894MHz (US Cellular, Band 5)
- 880-960MHz (GSM900, Band 8)
- 1.71-1.88GHz (DCS1800, Band 3)
- 1.85-1.99GHz (PCS1900, Band 2)
- 1.92-2.17GHz (IMT2100, Band 1)
- 1.71-2.17GHz (AWS, bands 4-10)
- 2.4-2.5GHz (WLAN2400, 802.11b/g/n)
- 2.5-2.69GHz (TDD LTE, Band 41 and FDD LTE, Band7)

which can be grouped into the following dual-broadband coverage: 700-960MHz and 1.7-2.7GHz [1].

Antenna proposed in this paper for handheld mobile terminal covers frequency bands 700-900 MHz and 1.7-2.7GHz.The design strategy involves a non-resonant type of antenna known as coupling element for the lower band (700-900MHz) operation. Since at lower frequency bands the ground plane of printed circuit board (PCB) acts major radiator (90% of the total radiation comes from PCB at 900MHz and 50% at 1800 MHz) as stated in [2-4].coupling element is used to excite the chassis mode which are the resonant modes of the metallic part of the PCB structure(ground plane) [1-4].In the case of this antenna schema the currents are induced on the PCB ground plane by capacitive excitation and their strength is more near the resonant frequency of the PCB ground plane. The feeding method of antenna element is similar to that of monopole structure with no inductive contact to PCB ground plane and demonstrates a low quality factor thus high bandwidth potential. The antenna elements used for handheld terminal are basically smaller radiating structures which require a matching network (MN) for lower band operation and matching network is designed using SMD components. A second antenna is then used for high band (1.7-2.7GHz) operation which is again a monopole structure but this antenna structure is self –resonant in nature. Thus entire design makes use of two antenna structures which are different in terms of resonance induced and could be stated as a fusion of non-resonant (requiring a matching network) and self resonant structures.

II. EXCAVATED COUPLING ELEMENT APPROACH

The proposed novel strategy is based on fusion of a non resonant Coupling element and a self resonant antenna for handheld terminals covering 700-900MHz and 1.7-2.7GHz frequency bands. The low band coverage is achieved with a 3D coupling element structure used with a matching network while the high band coverage is then achieved by integrating a self resonating antenna with a separate feed. The coupling element deployed here is unique in nature compared to other proposed structures. Based on the current distribution on the coupling element metal region at the inner region is excavated to form what is mentioned to be an “Excavated coupling element” and this modification provides a additional space which was previously unavailable to integrate another antenna element for high band (1.7-2.7GHz) operation. A separate feed is used to excite this high band antenna structure and placed in a manner so that the mutual coupling is reduced. The entire design is discussed in three sections namely plain coupling element (CE) and excavated CE, high band antenna structure and integration of high band antenna with excavated CE.

A. Plain and Excavated Coupling element

The plain coupling element structure has rectangular metal sheet of (59x14x0.07mm3) placed 3mm vertically above the substrate (FR4). The coupling element is fed from the centre of printed circuit board through a vertical feeding strip and the Printed circuit board has dimensions 114x59x0.8 mm3 with a ground clearance of 14mm under the coupling element. Antenna structure which can be seen in Fig. 1.

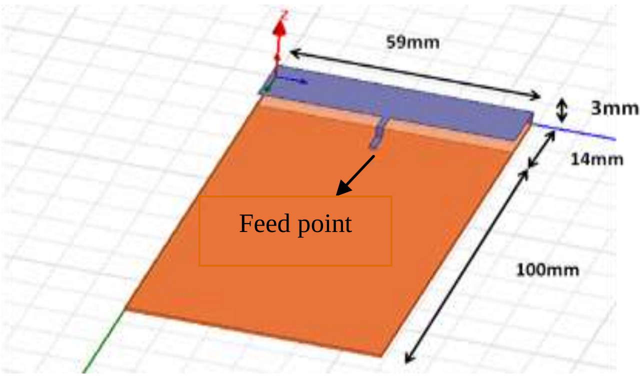


Fig.1. Antenna structure of plain coupling element.

The quality factor studies carried out in [6] suggest that a strong coupling could be achieved by placing the coupling element structure in z direction where in coupling is better near the corners of the ground plane. As the coupling element is not the principle radiator and used to couple the ground plane radiation modes it can be further reduced. Looking for such a possible reduction E-field simulations of the plain CE was carried out in Ansoft HFSS which can be observed in Fig.2.

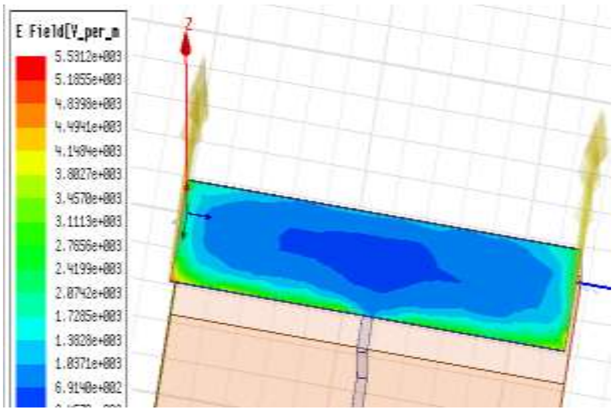


Fig. 2 Electric field under plain coupling element

The electric field under the plian coupling element is relatively weaker in the centre portion of the coupling element structure.An attemp is made to excavate the metal of entire mid portion coupling element and have a rectangular frame of 1mm. The E-field distribution of this excavated structure can be seen in Fig.3.When compared both the plain CE and excavated CE have similar distribution of E-field, however the E-field under excavated CE is weaker than E-field of plain CE.

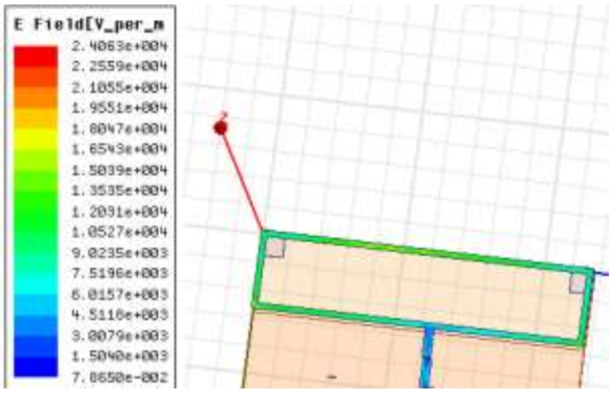
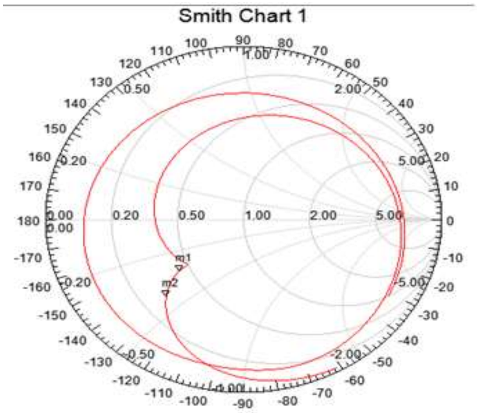


Fig. 3 Electric field under Excavated coupling element

The excavated coupling element is fed using a matching network is created using SMD components interconnected by micro strip lines. The design process involves plotting s11 on smith chart to obtain antenna impedance as shown in Fig.4.This impedance value is used to devise a matching network which is then subjected to manual optimization runs in Ansoft HFSS. The matching network is created using smith chart tool Smith V3.10 can be seen in Fig.5.



Name	Freq	Ang	Mag	RX
m1	0.9000	-137.4517	0.4304	0.4478 - 0.3199i
m2	0.8300	-131.4056	0.5887	0.3075 - 0.4155i

Fig.4. Impedance of Coupling element

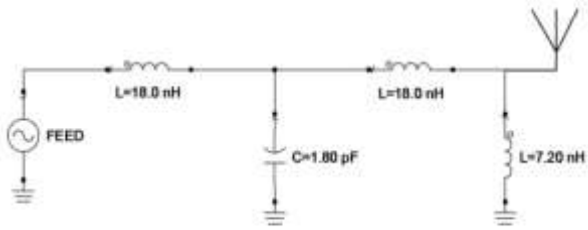


Fig. 5. Optimized matching network used at the LB antenna

B. High band antenna structure

Printed monopole radiating element has length of λ/4 which is slightly adjusted in order to obtain response in desired frequency band of LTE. The design tried to follow the methodology adopted in [5] and [7] which imparts monopole antenna with enhanced bandwidth characteristics. Initially a simple folded monopole antenna was induced to operate around 1.9 GHz having length around λ/4=36mm. This simple monopole antenna used initially is then subjected to bandwidth enhancement techniques in [7], which involves techniques like increasing the width of portion L of the monopole antenna and inducing step kind of structures around the edges. This step like structures helps in producing broadband response.High band antenna structures can be seen in Fig. 5

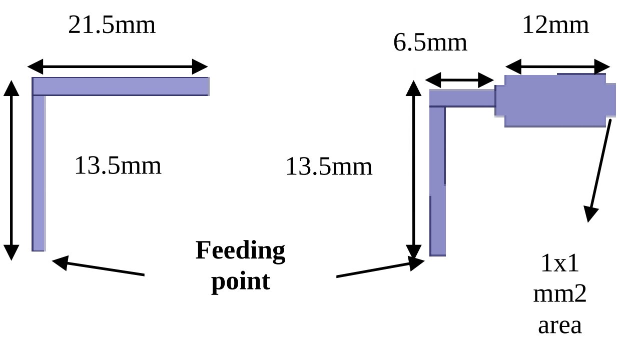


Fig. 6. High band antenna structures

C. Integration of High-Band Antenna within the ExcavatedCE

In the first part of this section, a space was gained by excavating plain coupling element and a matching network was designed to make the antenna structure operate in the low band. A strategic use of this space can now be done to incorporate a high-band antenna. Such a Strategic use of the space obtained was conducted in two folds, firstly a simple printed monopole antenna was deployed to obtain response in the designated high band which then followed by a second fold of employing certain broad banding techniques to get a broad banded response. The antenna structure used for high band operation is a simple structure directly printed on FR4 substrate and thus easier to design. Since we noticed that E-field beneath the excavated coupling element in the centre of the excavated region is weak (Fig. 2), the high band antenna was placed in this location to obtain high port-port isolation and a beneficial coupling with the matching network also aids in isolation. The bandwidth obtained for simple printed monopole antenna and that with the broad banded monopole antenna for high band operation can be observed in Table. I.

TABLE I COMPARISON OF TWO HB ANTENNA ELEMENTS

HB Antenna	Centre frequency(GHz)	Bandwidth (MHz)
Monopole	1.8	62
Modified monopole	1.8	113

Optimization of the matching network is also carried out at this stage manually to fine tune the overall structure to negotiate coupling effects on the response of both the antenna structures. The optimized layout of the proposed antenna can be seen in Fig. 6. The total PCB dimensions are 114×59×0.8mm3, with a ground clearance region of 59×14mm2, reserved for both antennas. The optimized HB antenna is a simple monopole which is placed 8.5mm away from the edge of the PCB.

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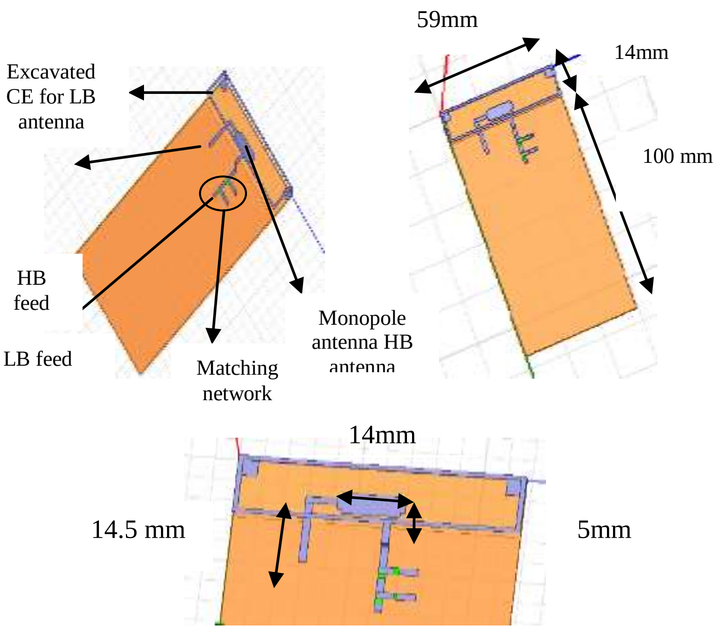
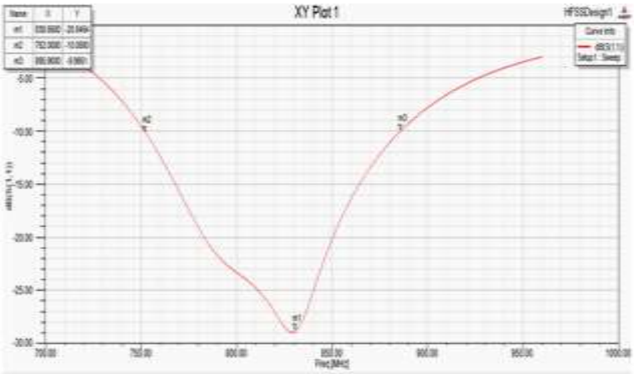


Fig . 7 .Optimized layout of the proposed antenna

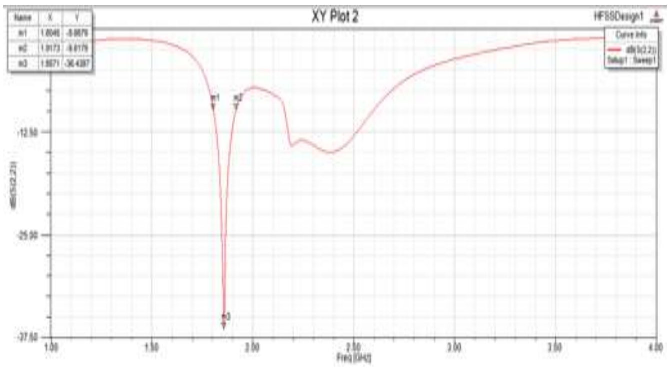
III. SIMULATION RESULTS AND DICUSSION

A. Antenna S parameter simulations

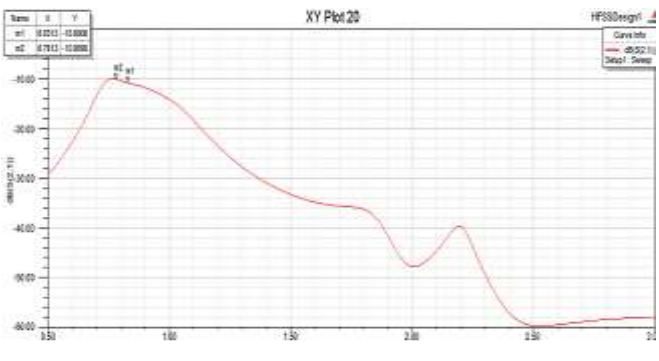
When high band antenna is incorporated the S-parameter seen in Fig.8 are obtained. The target low band 700-960MHz and high band 1.7-2.7 GHz are covered with a reflection coefficient of -10dB and port to port isolation is generally greater than 10 dB between 700-960MHz while for the high band 1.7-2.7GHz the isolation is greater than 37 dB. Further it can observed in the S12 curve that there is stop band behavior exhibited by coupling element in the frequencies 1.7 -2.7 GHz which is an indication of isolation between two antenna structures. Simulation results for all S-parameters like S11, S22, S12 and S21was can be observed in Fig.8. Firstly the S11 gives us the coupling element response which resonates at 830 MHz .These simulations were carried out in an iterative fashion by adjusting the values of lumped components in matching network in order to obtain desirable resonance at desired frequency.



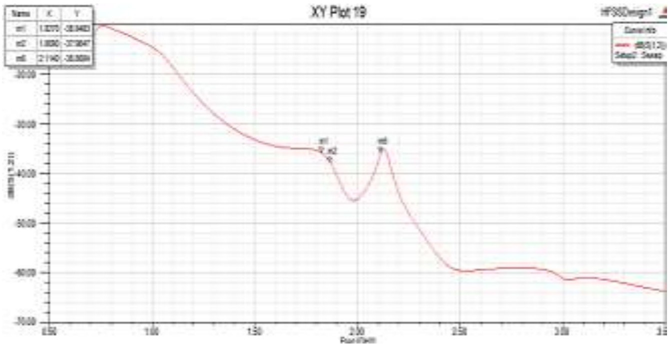
(a)



(b)



(c)



(d)

Fig.8 S-parameter curves for optimized antenna structure presented in Fig.7 (a) S11 curve (b) S22 curve (c) S12 curve (d) S21 curve

The return loss and the bandwidth obtained for two antennas integrated can be summarized in table II as follows

TABLE II ELECTRICAL PROPERTIES OF HEAD

Integrated Antenna	Bandwidth in MHz	Centre frequency in MHz
Excavated CE	133	830
Monopole antenna	113	1.8

B. Antenna 2-D gain pattern simulations

The 2-D gain pattern for different cut planes was observed for both CE and monopole antenna at 800 MHz and 1.8 GHz. In low band, a dipole-type of radiation is seen (as expected) since the main radiator is the ground plane. In either the low band or high band, has no wide-angle deep nulls as seen in the radiation patterns which is an prioritized aspect for mobile phone communications where the base-station orientation is never known in advance which are as follows

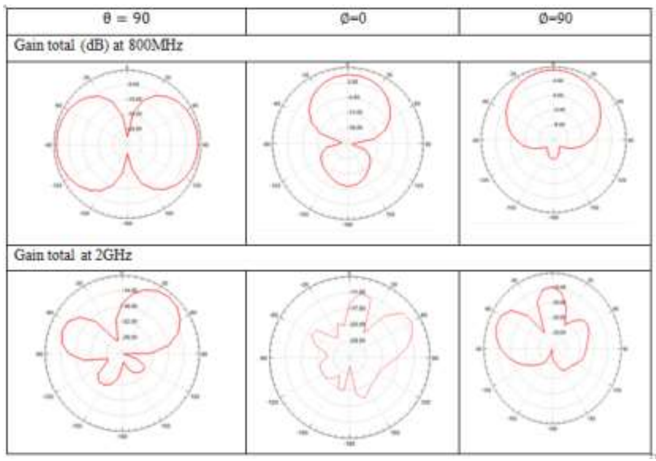


Fig . 9.2-D gain patterns

B. Specific absorbtion rate simulation

The specific absorption rate gives the amount of radiation absorbed by the tissues of human beings or other living organisms and is measured in terms of watts per kilogram. The SAR is defined in terms absorption averaged over 10 g of tissue which is the standard adopted by FCCI. The Indian government has set the value at 1.6 averaged over 10g of tissue. To estimate the SAR value of the proposed antenna design an approximate model of human head is created in Ansoft HFSS with the help of the electrical properties of the brain referred from [11] and properties referred are enlisted in Table III .The simulation model of human head consists of a conducting medium enclosed by a non conducting glass shell having thickness of 5 mm and dielectric constant εr =4.6.It is a container of the brain-equivalent liquid in testing situations.

TABLE III ELECTRICAL PROPERTIES OF HEAD

	permittivity		Conductivity		density
	@800MHz	@1.8GHz	@800MHz	@1.8GHz	Gm/ cm^3
Brain	43.5	40.5	0.872	1.40	1.4
Outer layer	4.6	4.6	0.003	0.001	1.6

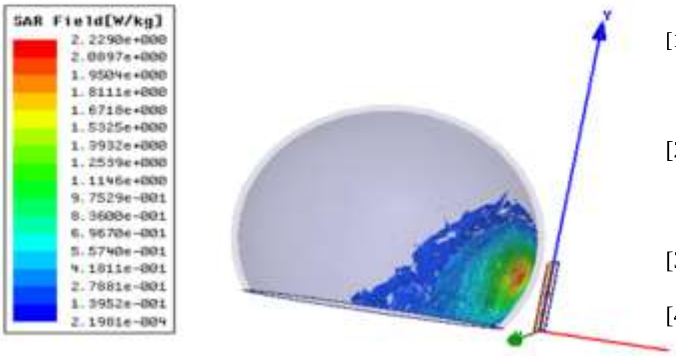


Fig . 10. SAR simulation at 800 MHz

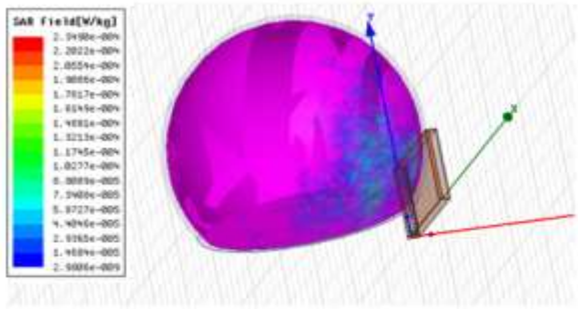


Fig . 11. SAR simulation at 1800 MHz

The simulated values of SAR is summarized in the table IV as follows

TABLE IV SAR VALUES OBTIANED

Antenna	SAR@ 800 MHz in W/Kg	SAR @ 2 GHz in W/Kg
Excavated coupling element with monopole antenna	2.22	0.00023

IV. CONCLUSION

A novel approach for antenna designs targeting 700-960MHz and 1.7-2.7GHz operation in handheld terminals has been presented in this paper. This approach consists of using a Coupling element which excavated by removing the metal inside for 700-960MHz coverage with negligible performance trade-off. In this manner, the space inside and underneath the coupling element is availed for the incorporation of another antenna to cover the 1.7-2.7GHz band, with a separate feed. To achieve high port-to-port isolation, the high band antenna is placed in a weak E-field region and also the matching network are optimized to ensure band-stop behavior in the operating frequency of the neighbor antenna.

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