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Analytical Study of Specific Absorption Rate Distribution on Different Antennas Operating At 2.4 Ghz Using HFSS

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Abstract

Now-a-days antennas became an integral part of most of the communication systems in our regular usage. The design of any antenna should follow some rules and regulations and certain standards according to the electromagnetic compatibility. Especially while using mobile phones, measurement of specific absorption rate is one of the key parameter to identify the reliability of the device as per the biological effects is concerned. This paper focus on the analytical study of SAR on 3 different types of antennas that we use commercially in our day to day life along with advanced communication systems. A dipole, a rectangular micro strip and a Planar Inverted Folded Antennas are taken in this study and their comparative analysis based on antenna parameters and Specific Absorption Rate is carried out in this work. Finite element method based Ansys HFSS tool is used to analyze these three models at an operating frequency of 2.4 GHz.

Keywords: Dipole, Rectangular microstrip, Planar Inverted Folded Antenna (PIFA), Specific Absorption Rate (SAR).

Introduction

Antenna engineers take so many considerations and standards while designing the antenna models. The design considerations may be in the form of materials used, size of the antenna, efficiency of the antenna, radiation characteristics and its effects [1-6]. Now-a-days most of the electronic gadgets and communication systems are holding multiple number of antennas in their body. By placing these number of antennas on a particular system will affect the human beings who are working nearer to that and who are placing those gadgets nearer to their body. The powerful electromagnetic emissions from the antennas will effect negatively on human beings in one way or the other [7-12].

Radar like high electromagnetic radiation emission systems will affect human beings, animals and some of the living plants mostly in a negative way. The people who are working nearer to those devices will be affected more by electromagnetic wave propagation. In our regular life the usage of cell phones, tablets, laptops became quite common and which will radiate more are less some amount of power. For these devices a specific parameter is to be calculated to determine its electromagnetic compatibility [13-15]. SAR is defined by the Federal Communication Commission (FCC) as being a measure of the amount of radio frequency energy absorbed by the body when using a mobile phone.

$$SAR=\int_{sample} \frac{\sigma(r)|E(r)|^2}{\rho(r)} dr \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The specific absorption rate of any antenna can be calculated before coming into the production, with the use powerful electromagnetic tools like HFSS, CST, FEKO etc. These tools give a convenient approach to determine the SAR with its simulation capability. This paper mainly focuses on the design aspects of the dipole, rectangular micro strip and PIFA antennas and their parameters at the initial stage [16-20]. After the design of these models for a particular frequency of operation the specific absorption rates are simulated and a comparative study is presented with the standard specifications. A human head like bowl shaped tissue is designed in the HFSS with standard permittivity and permeability. The proposed antennas are placed nearer to the bowl shaped tissue and its SAR readings are tabulated for each case.

Antenna Design and Geometry

Design of Dipole Antenna

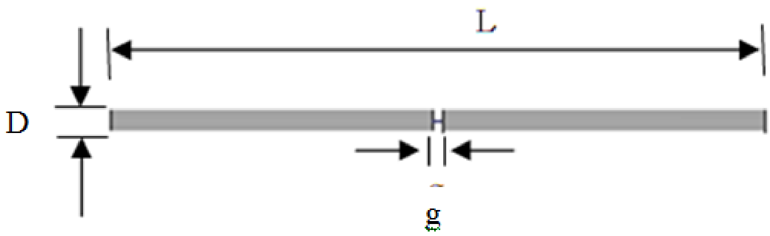

Figure 1: Basic Dipole antenna

The length of antenna will be slightly shorter than that calculated for a wave travelling in free space. Length of the antenna can be calculated with formula:

$$L = \frac{150*A}{f} = A\frac{\lambda}{2} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where f is resonant frequency and A is Multiplication factor that lies between 0.96 and 0.98, and can be obtained from the following graph. Value of A depends upon the ratio of length of antenna to the thickness of the wire.

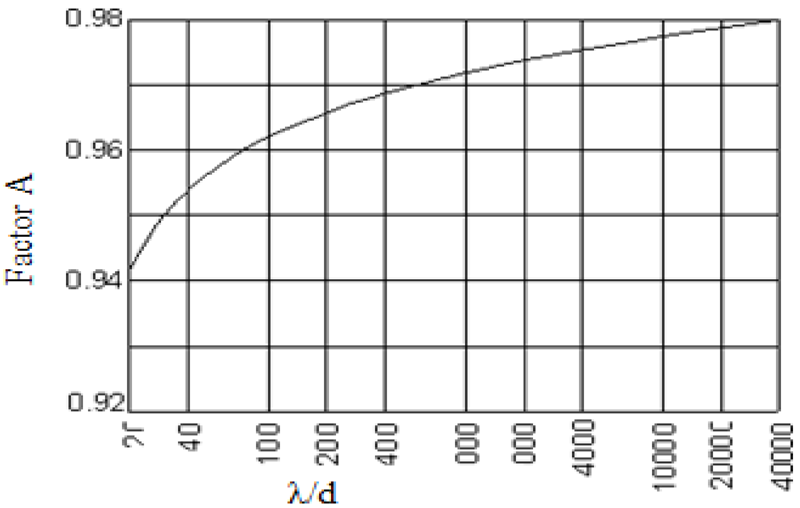

Figure 2: Multiplication factor A chart (Courtesy by Google Images)

$$g = \frac{L}{100} \quad (3)$$

$$R = \frac{D}{2} = \frac{\lambda}{1000} \quad (4)$$

Where g is Feeding gap of antenna, R is radius of antenna, λ is wavelength. g should be minimum for the dipole to obtain uniform current distributions to both arms.

Rectangular Micro Strip Antenna

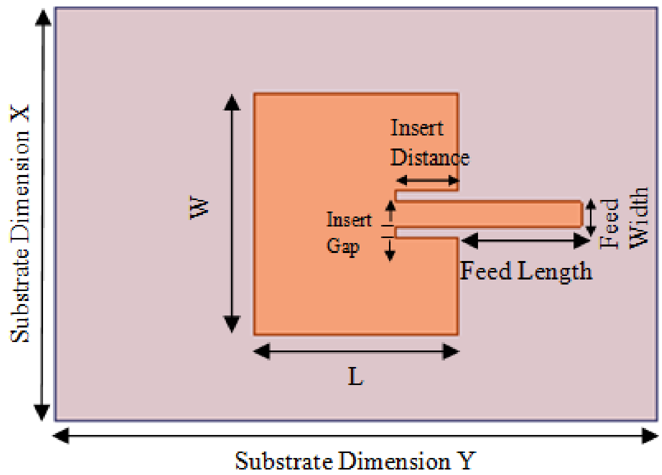

Figure 3: Rectangular Microstrip Patch Antenna

ε_{reff} (Effective Dielectric constant) = $\varepsilon_{reff} = \left(\frac{k_z}{k_0}\right)^2 = \frac{\omega^2 \mu_0 \varepsilon_{eff}}{\omega^2 \mu_0 \varepsilon_0} = \frac{\varepsilon_{eff}}{\varepsilon_0}$

Where

ω = angular velocity,
μ_0 = permeability and
ε_0 = permittivity

When $\frac{w}{h} > 1$ (where w = width, and h = height of the substrate)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \text{..............................} \quad (5)$$

We observed that at lower frequencies, the ε_{reff} is slowly increasing and when moving towards higher frequency the ε_{reff} is almost constant even though there is change in permittivity.

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \text{...........................} \quad (6)$$

Where ΔL is change in length.

$$\left(f_{rc}\right)_{010} = \frac{v_0 / \sqrt{\varepsilon_{reff}}}{2\left[L + 2\Delta L\right]} = g \frac{v_0 / \sqrt{\varepsilon_r}}{2L} \text{..............................} \quad (7)$$

Where g = fringe factor (length reduction factor)

$$L_{eff} = L + 2\Delta L \text{....................................} \quad (8)$$

$$\left(f_r\right)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0 \varepsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \text{..............................} \quad (9)$$

$$\left(f_{rc}\right)_{010} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0 \varepsilon_0}} = \frac{v_0}{2\left(L + 2\Delta L\right)\sqrt{\varepsilon_{reff}}} \text{..............} \quad (10)$$

The resonant frequency with fringing is given by

$$\left(f_r\right)_{010} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \text{..} \quad (11)$$

Because of fringing the effective distance between the radiating edges seems larger than L by an amount of ΔL at each edge. This causes the actual resonant frequency to slightly less than f_{ro} by a factor q. Thus

$$\left(f_{rc}\right) = \frac{v_0}{2(L + 2\Delta L)\sqrt{\varepsilon_{reff}}} = q \frac{v_0}{2L\sqrt{\varepsilon_r}} \text{.................} \quad (12)$$

Planar Inverted Folded Antenna

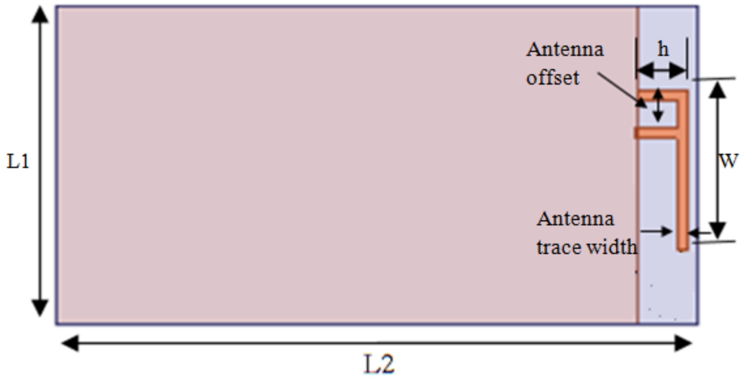

Figure 3: Planar Inverted Folded Antenna

PIFA is widely used in mobile phones because of its good SAR properties, low profile, and Omni directional pattern and resonates at quarter-wavelength.

The resonant frequency of the PIFA depends on width W. If the ratio of width W and length L1 is equal to unity then length L1 is equals to quarter wavelength.

$$L1 + L2 = \lambda/4 \quad (13)$$

When W/L1=1 then

$$L1 + H = \lambda/4 \quad (14)$$

Suppose that width W is equal to zero that the short is just a pin then we will assume that width W is far less than length L2 then the planar inverted folded antenna will resonate at quarter wavelength.

When W=0 then

$$L1 + L2 + H = \lambda/4 \quad (15)$$

The width W of PIFA depends on its resonant frequency. Width W increases with increase in resonant frequency and bandwidth characteristics of antenna can be changed by the position of the feed point

$$\varepsilon_{eff} = \frac{e_r + 1}{2} \quad (16)$$

$$L2 = \frac{0.01988}{\sqrt{\varepsilon_{eff}}} \quad (17)$$

$$f_r = \frac{c}{4\sqrt{\varepsilon_{eff}}(l1 + l2 - w + h)} \quad (18)$$

Table 1: Dimensions of Dipole, Patch and PIFA Antennas

S. No	Antenna	Variable	Value
1	Dipole	Frequency	2.4GHz
		Dipole length	5.62 cm
		Dipole radius	0.094 cm
		Feed gap	0.094 cm
2	PIFA	Frequency	2.4GHz
		Antenna length1	2.46cm
		Antenna length2	0.79cm
		Antenna trace width	0.15cm
		Antenna offset	0.44cm
		Feed offset	-0.49cm
		Feed length	0.015cm
		Feed width	0.15 cm
		Substrate thickness	62 mil
		Substrate dimension along X	4.9cm
		Substrate dimension along Y	9.9 cm
3	Patch	Frequency	2.4GHz
		Patch dimension along X	4.94 cm
		Patch dimension along Y	4.14 cm
		Substrate thickness	62 mil
		Substrate dimension along X	8.4 cm
		Substrate dimension along Y	12.34cm
		Insert distance	1.263cm
		Insert gap	0.243cm
		Feed width	0.485cm
		Feed length	3.807cm

Results and Discussion

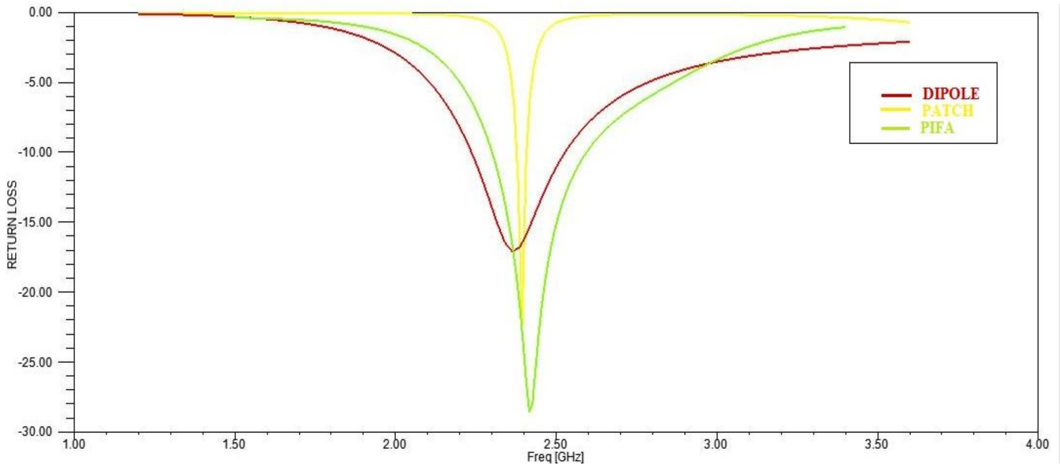

Figure 5: Return Loss Curve For Three Antennas

Before finding the specific absorption rate of the three antenna models, we measured the return loss and plotted in the figure 5. The return loss curve shows the resonant frequency of these models at 2.4 GHz with different impedance band widths for different antennas. The dipole antenna is showing bandwidth of 400 MHz between 2.2 to 2.6 GHz. A rectangular patch antenna shows narrow bandwidth at the resonant frequency of 2.4 GHz. The Planar Inverted Folded Antenna shows a considerable bandwidth of more than 350 MHz and minimum return loss at the resonating frequency. Out of these three models PIFA antenna shows better impedance bandwidth of 34% at the resonant frequency of 2.4 GHz.

The Specific Absorption Rate of these three antenna models are examined by considering a bowl shaped human head tissue nearer to the designed models. The resonant frequency of the antenna models are fixed at 2.4 GHz and the Specific Absorption Rate is plotted using HFSS tool. Figure 6 shows the dipole antenna Specific Absorption Rate at the resonant frequency 2.4 GHz the SAR plot is created by considering each layer, that means brain and skin regions are recognized to be the most important-the brain because of its critical functions for survival and skin because of its close proximity to the antenna. It has been observed that a Specific Absorption Rate almost 5W/Kg is obtained for the case of dipole antenna. Figure 7 shows the Specific Absorption Rate of patch antenna which shows 1.39W/Kg SAR at the resonant frequency 2.4GHZ.

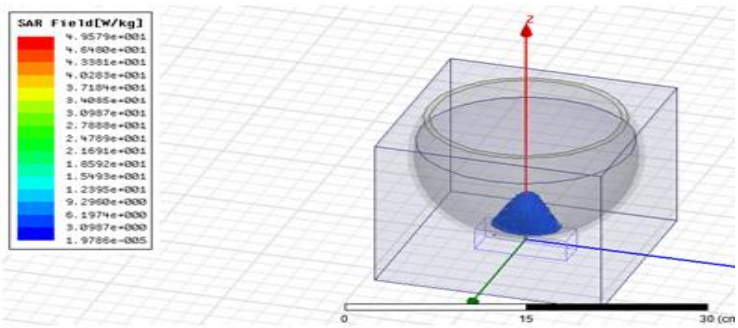

Figure 6: Dipole antenna Specific Absorption Rate

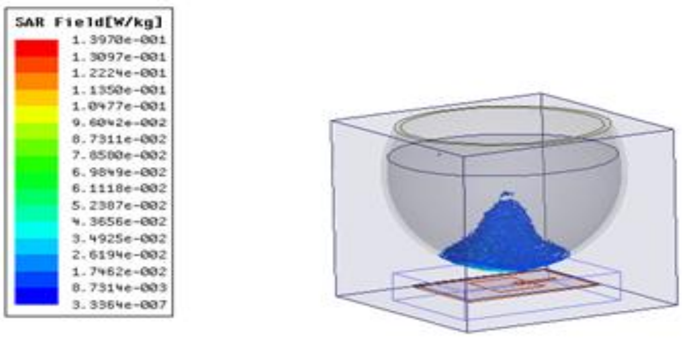

Figure 7: Patch antenna Specific Absorption Rate

When planar inverted folded antenna is used in the SAR test, it is been observed that a SAR value of 1.85W/Kg at the resonant frequency in fig 8. The patch antenna case is showing the lowest SAR value of the three and an interesting radiation pattern in the vertical direction. The Indian government identified the safety limit to be 1.6W/Kg. While the US also uses the same limit these values are the maximum SAR points when averaged over 1gm of tissue for the limit.

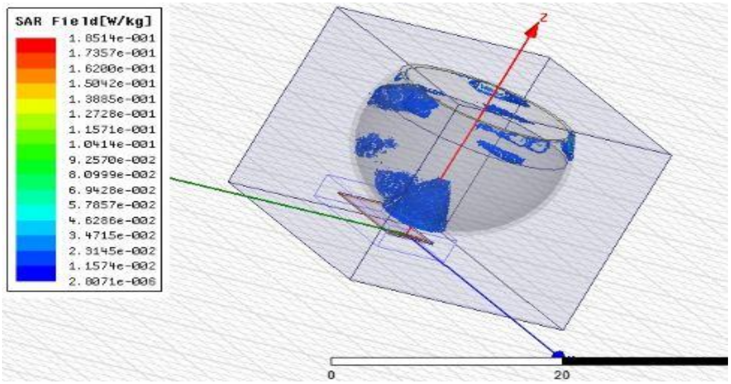

Figure 8: PIFA antenna Specific Absorption Rate

For all the designs considered here the maximum SAR was found for the case of dipole antenna that too located on the skin, a logical reduction because of its close proximity to the source. In general planar inverted folded antenna is preferable for mobile phone applications compared with any other type of antennas. In this study we observed the specific absorption rate more than 1.8W/Kg for the case of PIFA antenna. This can be reduced by choosing the radiating element in perpendicular to the source and choosing proper material with minimum loss while designing the antenna. This result cannot be applied universally to all the PIFA antennas, as each consisting of separate geometry, cover material etc. However if certain improvements are taken in the research of these models, we can improve the performance of the mobile antennas with low SAR.

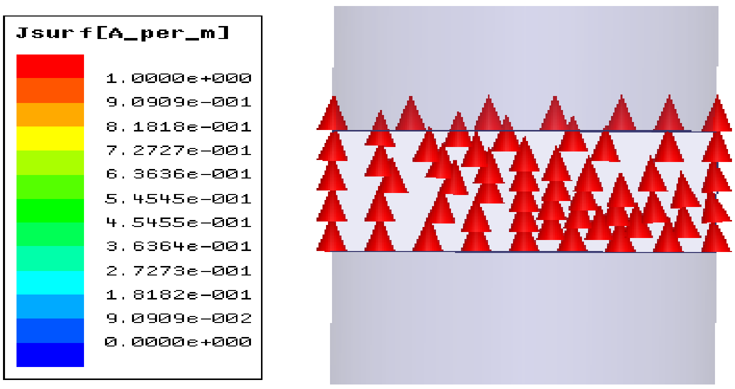

Figure 9: Current Distribution in dipole at 2.4 GHz

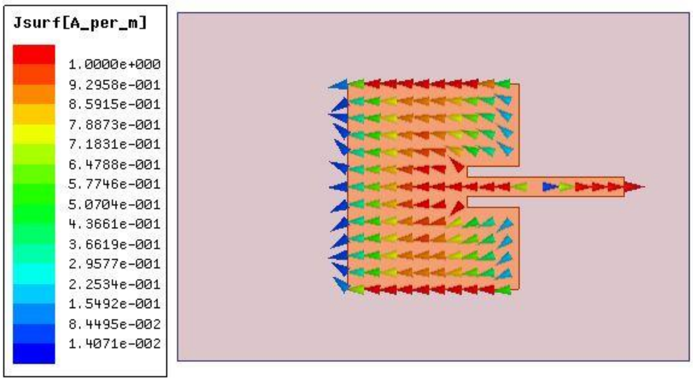

Figure 10: Current Distribution in Rectangular Patch at 2.4 GHz

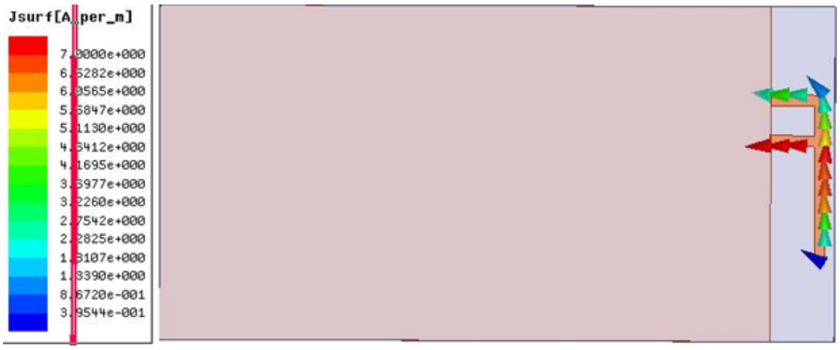

Figure 11: Current Distribution In Planar Inverted Folded Antenna At 2.4 Ghz

Fig 9 shows current distribution in dipole antenna at feed point. The maximum current intensity is focused towards vertical direction as shown in figure 9. Figure 10 sows the current distribution in the rectangular patch antenna at 2.4 GHz. the current orientation is towards Y direction and the patch surface and on the feed line the magnitude of the current elements similar to the patch surface current elements magnitude but opposite to polarity. The intensity on the surface is decreasing with the distance travelled by the current elements. Maximum intensity is focused on the centre of the patch and on the edges towards X direction.

Figure 11 shows the current distribution over the inverted F shape radiating element in the planar inverted folded antenna. The current elements are following the particular direction that means the distribution is towards the feed element with maximum intensity at intersection point of radiating element and the substrate material

Conclusion

The present study deals with the analysis of three different antennas with respect to their specific absorption rate coefficient. The three models i.e., dipole, rectangular patch and planar inverted folded antenna are been tested in this work with respect to all the aspects like reflection coefficient, radiation mechanism and distribution of surface current etc. The specific absorption rate should be less than 1.6 W/Kg in general for any antenna which can be used in the mobile applications. It has been observed that these three antennas are generating different specific absorption rate values compared to the standard SAR approve value. The dipole antenna is producing more SAR compared to other two models, surprisingly the actual antenna which should be used in mobile handsets that means PIFA antenna also crossing the standard SAR value. Depending on the application we can use PIFA or planar patch antenna at the desired band of frequency of operation. The specific absorption rate can be reduced by taking special care in the design of the antenna models and by controlling radiation mechanism with proper feeding. This study gives the marginal analysis regarding the usage of these antennas in the desired band of operation with specific application. It will not provide the complete solution for the selection of the exact model and controlling of radiation mechanism in all aspects.

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References

[1] B.T.P.Madhav, Prof. VGKM Pisipati, K V L Bhavani, P.Sreekanth, P.Rakesh Kumar, "RECTANGULAR MICROSTRIP PATCH ANTENNA ON LIQUID CRYSTAL POLYMER SUBSTRATE", Journal of Theoretical and Applied Information Technology, Vol 18, No 1, August 2010.

[2] B.T.P.Madhav, Prof. VGKM Pisipati, Prof. Habibulla Khan, VGNS Prasad, Prof. KSN Murty , "ULTRA WIDE BAND LIQUID CRYSTAL POLYMER MICROSTRIP ELLIPTICAL PATCH ANTENNA", Journal of Theoretical and Applied Information Technology, Vol 20 No 1, October 2010.

[3] B.T.P.Madhav, Prof. VGKM Pisipati, N.V.K Ramesh, Prof. Habibulla Khan, Prof. P.V.Datta Prasad, "PLANAR INVERTED-F ANTENNA ON LIQUID CRYSTAL POLYMER SUBSTRATE FOR PCS, UMTS, WIBRO APPLICATIONS", ARPN Journal of Engineering and Applied Sciences, VOL. 6, NO. 4, APRIL 2011 ISSN 1819-6608. Cited by 2.

[4] D.Rakesh, P.Rakesh Kumar, B.T.P.MADHAV, Prof. Habibulla Khan K Ch Sri Kavya, K.Prabhu Kumar, S Bala Durga Prasad, "Performance Evaluation Of Microstrip Square Patch Antenna On Different Substrate Materials, Journal of Theoretical and Applied Information Technology, www.jatit.org, Vol 26 No 2, April 2011.

[5] K.Prabhu Kumar, Dr.P.S.Brahmanandam, B.T.P.Madhav , K Ch Sri Kavya, V.Shiva Kumar, T.RaghavendraVishnu, D.Rakesh, UNIPLANAR QUASI YAGI ANTENNA FOR CHANNEL MEASUREMENTS AT X BAND, Journal of Theoretical and Applied Information Technology, www.jatit.org, Vol 26 No 2, April 2011.

[6] B. T. P. Madhav, V. G. K. M. Pisipati, , D. Madhavi latha and P. V. Dattaprasad, “Planar Dipole Antenna on Liquid Crystal Polymer Substrate at 2.4 GHz”, Solid State Phenomena Vols. 181-182 (2012) pp 289-292,Trans Tech Publications, Switzerland.

[7] P. W. Barber, O. P. Gandhi, M. J. Hagmann, and I. Chatterjee, “Electromagnetic absorption in a multilayered model of man,” IEEE Trans. Biomed. Eng., vol. 26, no. BME-7, pp. 400–405, Jul. 1979.

[8] J. Wang, O. Fujiwara, S. Watanabe, and Y. Yamanaka, “Age effect of spatial peak absorption rate of dielectric tissue properties of head for 900 MHz mobile telephones,” IEEE Trans. Electromagn. Compat., to be published.

[9] Foster, K.R., Moulder, J.E. Wi-Fi and health Review of current status of research Health Physics, vol. 105, No. 6, pp. 561-575, 2013.

[10] B.T.P. Madhav, VGKM Pisipati, Habibulla Khan, P.V. Datta Prasad, “Shorting Plate Planar Inverted Folded Antenna on LC Substrate for Bluetooth Application”, Journal of Engineering Science and Technology Review, ISSN: 1791-2377, Vol 5, Issue 2, (2012) , pp 42-45

[11] Andreas Christ et al. The Virtual Family development of surface-based anatomical models of two adults and two children for dosimetric simulations Phys. Med. Biol. 55 N23, 2010.

[12] Rammal, M., Jebai, F., Rammal, H., Joumaa, W.H. Effects of long-term exposure to RF/MW radiations on the expression of MRNA of stress proteins in Lycospersicon esculentum. WSEAS Transactions on Biology and Biomedicine, 11, pp. 10-14, 2014.

[13] B.T.P. Madhav, K.S.L. Soumya and Girish Dasari, “Design and Parametric Simulation of Planar Inverted Folded Antenna”, International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 9, Number 15, June 2014, pp. 2897-2902.

[14] W.-J. Liao, T.-M. Liu and S.-Y. Ho, “Miniaturized PIFA Antenna for 2.4 GHz ISM Band Applications,” IEEE Proceedings of the 6th European Conference on Antennas and Propagation (EUCAP), Prague, 26-30 March 2012, pp. 3034-3037.

[15] O. P. Gandhi, Q.-X. Li, and G. Kang, “Temperature increase for the human head for cellular telephones and for peak SARs prescribed in safety guidelines,” IEEE Trans. Microwave Theory Tech., vol. 49, pp. 1607–1613, Sept. 2001.

[16] B.T.P.Madhav, VGKM Pisipati1, Habibulla Khan, V.G.N.S Prasad, K. Praveen Kumar, KVL Bhavani and M.Ravi Kumar, “ Liquid Crystal Bow-Tie Microstrip antenna for Wireless Communication Applications”,

Journal of Engineering Science and Technology Review ISSN: 1791-2377, 4 (2) (2011) 131-134.

[17] M. R. Iqbal Faruque, M. T. Islam and N. Misran, SAR Analysis in Human Head Tissues for Different Types of Antennas, World Applied Sciences Journal, Vol. 11, N° 9, pp. 1089-1096, 2010.

[18] B.T.P.Madhav, S.S.Mohan Reddy, Neha Sharma, J. Ravindranath Chowdary, Bala Rama Pavithra, K.N.V.S. Kishore, G. Sriram, B. Sachin Kumar, "Performance Characterization of Radial Stub Microstrip Bow-Tie Antenna", International Journal of Engineering and Technology (IJET), ISSN: 0975-4024, Vol 5, No 2, Apr-May 2013, pp 760-764.

[19] B.T.P. Madhav, S.S. Mohan Reddy, J. Ravindranath Chowdary,V. Vinod Babu, S.S. Satya Parthiva, S. Kalyana Saravana, "Analysis of Dual Feed Asymmetric Antenna", International Journal of Applied Engineering Research, ISSN 0973-4562 Volume 8, Number 4, June-2013, pp. 361-367.

[20] P. Syam Sundar, B.T.P. Madhav, D. Sri Harsha, P. Manasa, G. Manikanta and K. Brahmaiah, "Fabric Substrate Material Based Multiband Spike Antenna for Wearable Applications", Research Journal of Applied Sciences, Engineering and Technology, ISSN: 2040-7459, Vol 8, Issue 3, pp 429-434, Oct-2014.