www.s2is.org
International Journal on Smart Sensing and Intelligent Systems
ISSN 1178-5608

SPECIFIC ABSORPTION RATE ASSESSMENT ON HUMAN HEAD DUE TO RADIATIONS BY MOBILE PHONE ANTENNA

[1*]M.Anto Bennet, [2]J.Surekha Poomathi, [2]C.Kalpana, [2]S.Sariga Priya

[1] Faculty of Electronics and Communication Department, vel tech, Chennai, India.

[2] UG Students of Electronics and Communication Department, vel tech , Chennai, India.

Email: bennetmab@gmail.com

Submitted: May 27, 2017 Accepted: June 15, 2017 Published: Sep 1, 2017

Abstract- Development of mobile phone communication infrastructure in the world has promoted which lead public concern over possible health effect exposure to radio frequency electromagnetic energy (RFEME) emanating from mobile phone antenna. The Micro-strip patch antenna plays an important role in electromagnetic energy transmitting and receiving phenomena in mobile phone. This paper makes an effort to assess the mobile radiation exposure effect on 4 years child, 8years child and an adult head model. Hand held device model having micro-strip antenna is used for human interaction. The software simulation performed by Computer simulation technique (CST) software based on Finite difference Time Domain Technique yields specific absorption rate and 3D-thermal distribution on spherical human head.

Index terms: Radio Frequency ElectroMagnetic Energy (RFEME) , Computer Simulation Technique (CST),Specific Absorption Rate (SAR),Magnetic Resonance Imaging (MRI)

I. INTRODUCTION

With the growth of recent use and estimated supplementary increases in the use of mobile phones and other private communication services, there has been substantial research effort dedicated to the interaction between antennas on handsets and the human body. To ensure public safety concerning radiofrequency exposure, the International Commission of Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE) have established guidelines and standard for limiting electromagnetic fields exposure. These guidelines and standard define basic restrictions, which specify SAR limits not to be exceeded. In INDIA the value of SAR should not exceed 1.6 W/kg beyond this limit is not permitted. When human are affected by the electromagnetic field ,the electrical property of the human body is changed like conductivity and permeability and some phenomena of the electromagnetic field like attenuation, diffraction, dispersion, reflection also occurs. But, to measure those phenomena inside the human body is quite difficult[1,2]. When the tissue of the human body absorb the radiation of the electromagnetic wave then the temperature of the human body tissue will increase because EM(electromagnetic) energy increase kinetic energy of the absorbing molecules. The electromagnetic energy absorb by the tissue will produce temperature that dependence on the cooling mechanism of the body tissue. When the thermoregulatory capability of the system is exceed, tissue damage result will occur. While placing mobile phone nearer to head, the emitted EM radiation gets coupled to human head tissues, which might alter the basic biological function of cells. Even, we can sense the temperature increment in outer case of handset as well as ear, where handsets are pressed while talking for longer hours shown in fig 1.

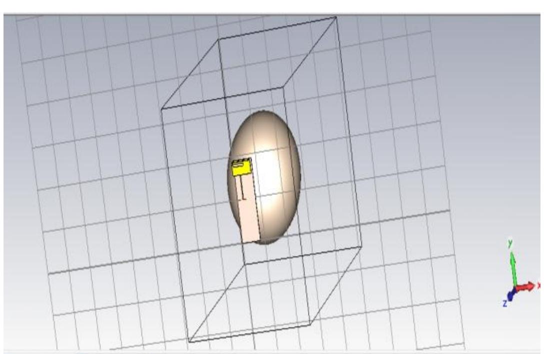

Fig: 1 Micro strip antenna with human head model consists of brain, skin and skull.

The temperature increment in human tissue is due to power coupled and it may vary with interacting environment. However, the sensed heat gets eventually decreased to equilibrium due to blood circulation. The consequences of excessive heating in the body vary from temporary disturbances in cell functions to permanent destruction of tissues. Areas with less efficient cooling by the circulation, e.g. the lens of the eye, brain cells are more susceptible to electromagnetic radiation[3,4]. Since, the usage of mobile phones is inevitable in this modern technological world, and the radiation exposure from mobile phone is non uniform, limits can be précised in terms of Specific Absorption Rate (SAR) with an averaging mass of 1 g and 10 g of tissue in the shape of cube. Further, heat induced in tissues signifies the well known adverse health effect at microwave frequencies.The analysis of power absorbed by the human head and the antenna performance are necessary for the compliance testing of mobile phones performance[7,8,9]. This coupled field can be efficiently calculated by numerical method based on finite difference time domain technique. This work endeavor to assess the health hazards, particularly the power absorbed by tissues and thermal effects due to exploitation of mobile phones. The work includes evaluation of specific absorption rate for children and adult with same electromagnetic environment. Results might enlighten the mobile phone users regarding radiation exposure effect from mobile phones and, ultimately results in the minimization of an individual's risks. Antennas are essential components of all equipment that uses radio. They are used in systems such as radio broadcasting, broadcast television, two-way radio, communications receiver radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones, Bluetooth-enabled devices, wireless computer networks, baby monitors, and RFID tags on merchandise [5,6].

II. PROPOSED SYSTEM

In the proposed system, micro strip antenna is designed using computer simulation software with finite difference time domain technique. Now a day's mobile phones are designed with printed circuit boards, hence we designed the micro-strip antenna for the human head interaction calculation of SAR value (specific absorption rate). The frequency range of micro-strip antenna is 0.5-3GHz. Mobile phone handsets are used by people of various age group and we make an effort to assess the mobile phone radiation exposure effect shown in fig2.

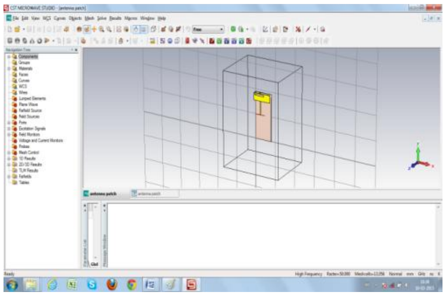

Fig:2 Micro-strip patch antenna design

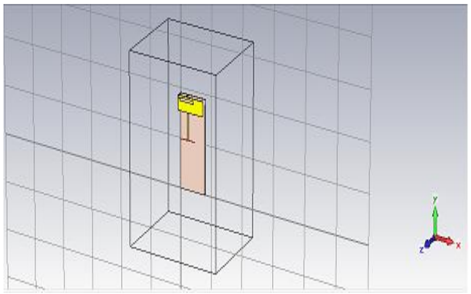

Fig 3. Micro strip patch antenna

Model development includes development of antenna model (micro strip patch antenna), Human head model (consists of brain, skin and skull) and Hand held device model.

III. ANTENNA MODEL:

In this work, Micro strip patch antenna is used with single excitation port is placed in free space .The length of the patch antenna is 95mm for operating frequency range of 0.5- 3GHz

In the design of micro-strip antenna, there are six different steps involved in the process using CST STUDIO SUITE in that we have to select a template depending upon application; here we are selecting Antenna (mobile phone) shown in fig3.

Step1: The solid 1 (Ground plane) is implemented, the length of ground plane is 95mm and the material used for this is copper (annealed). In the printed circuit boards, a ground plane is a large area of copper foil on the board which is connected to the power supply ground terminal and serves as a return path for current from different components on the board.

Step2: Solid 2 is for mobile phone cover, the length is same as ground plane and the material used here is FR-4 (lossy).FR-4(lossy) is selected because of its low cost.

Step3: Solid3 is implemented for main substrate cover (i.e, patch antenna cover) . The length of the main substrate cover is 15mm and material is used same as mobile phone cover.

Step4: Solid4 represents the patch antenna which is Z orientation. The length of the antenna is 0.07mm and different dimensions are given in the X and Y direction. The shape that is used for patch antenna is brick from extrude. The material used in the soild4 is copper (annealed).

Step5: Solid5 is short pin which is used to connect the ground plane with patch antenna. Here also the material is copper annealed.

Step6: Solid6 and solid7 are used for feed pin, which is used for the input power to the antenna. The material is copper annealed.

The lumped port excitation with 50 ohm internal resistance is located in the feed gap. Maximum working frequency of 3GHz is specified for excitation source. Antenna performance was analyzed in section conclusion by considering the parameters such as, the current distribution, S-parameter, starting with these initial requirements, we optimized the design through simulation using CST software package based on the Finite Difference Time-Domain technique. For analyzing SAR and thermal distributions, the near field environment may include a human head and antenna enclosed by a plastic frame, which may influence on antenna performance.

IV. HUMAN HEAD MODEL:

Table1. Properties of tissues in human model

Tissue	**Brain diameter(mm)**	**Skull thickness(mm)**	**Skin thickness(mm)**
4 years child	136.1	3.1	3.6

8 years child	140.6	3.5	4
Adult	160.1	8.9	7.2
Permittivity	52.7	12.5	35.2n
Conductivity	0.94	0.14	0.60

The user's head (4 years child, 8 years child and adult) was modeled as a sphere with three layers such as skin, skull and brain, using CST software. Human body tissues have different values of dielectric properties that is, permittivity and conductivity and these properties are the function of several variables such as frequency, geometry and size of tissue, and water contents shown in table 1.

V. HUMAN HEAD DEVICE MODEL:

Hand held device model

A handheld device model used for human interaction was modeled by CST. Figure shows the interaction of handheld geometric model which has a maximum dimension 167mm *23mm*83mm with spherical human head. Components considered for simulation are feeding port (patch antenna), plastic cover (eε =4.4) and plastic cover was modeled as dielectric materials.

VI. MEASUREMENT OF POWER ABSORBED

SAR is a measure of the rate at which energy is absorbed by the body when exposed to a RF electromagnetic field. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). SAR is usually averaged either over the whole body, or over a small sample volume (typically 1 g or 10 g of tissue).

SAR= (σ(E) ^2)/ (2ρ)----------------------(1)

Where, E is the effective value of the electric field intensity (V/m), σis the electric conductivity (S/m),ρis the mass density(Kg/m3) and

The unit of specific absorption rate is W/kg .Due to evolution in wireless technologies; dosimetric evaluation of handheld device is highly desirable for safety environment.For radio frequency signals, SAR value is calculated for either 1g (Australia, United States) or 10g (Europe, Japan) of simulated biological tissue in the shape of a cube. Partial (localized) non occupational exposure is limited to a spatial peak value not exceeding 1.6 W/kg. The partial exposure SAR limit recommended by the council of the European Union and adopted by India is also 1.6 W/kg.SAR is used to measure exposure to fields between 100 kHz and10 GHz. It is commonly used to measure power absorbed from mobile phones and during magnetic resonance imaging (MRI) scans. The value will depend heavily on the geometry of the part of the body that is exposed to the RF energy and on the exact location and geometry of the RF source. For example, head in a talk position. The SAR value is then measured at the location that has the highest absorption rate in the entire head, which in the case of a mobile phone is often as close to the phone's antenna as possible.Tissues are made up of water, different salts and organic compounds and they can be considered as a mixture of insulators and conductors. Brain tissue is rich in water along with fat content and cerebrospinal fluid along the ventricles and extends to flow along spinal cord. When a portable cellular telephone is in the typical use position, the nearest brain tissue is in matter of relatively uniform dielectric characteristics with macroscopic values of dielectric constant and conductivity $\varepsilon r = 52.7$ and $\sigma = 0.94$ S/m in the frequency band of interest shown in fig 4.

Figure: 4. Head in a talk position to measure SAR value.

VII. THEORITICAL CALCLATION:

SAR is amount of radiation which is absorbed by the human tissues while using the cell phones. When the SAR rate is very high it represents the radiation absorbed is also very high. This SAR value is usually measured in units of watts per kilogram (W/kg) in either 1 or 10 gram of tissue shown in table 2.

$$\mathbf{SAR= (\sigma E^2)/2\rho}\text{--------------------------------------}\mathbf{(2)}$$

Where, E is the induced electric field strength (V/m) in tissue, ρ is the tissue density (kg/m^3), σ is the conductivity of the material. The skin induced electric field can be calculated to be 17.983V/m. Therefore, the SAR in head skin can be calculated.

$$SAR=\sigma E^2/2\rho=1.25*(17.982)^2/2*1010 =0.2000942\ W/kg.\text{-----------}(3)$$

The induced electric field for skull can be calculated to be 22.069V/m. Therefore, the SAR in head skull can be calculated.

$$SAR=0.45*(22.069)^2/2*1810=0.06054\ W/kg\text{-----------------}(4)$$

The Brain induced electric field can be calculated to be 6.96V/m and the SAR is determined as:

$$SAR=1.29*(6.96)^2/2*1040=0.030043\ W/kg.\text{----------------------}(5)$$

Tables: 2.calculated SAR value

Tissue	**Conductivity**(S/m)	**E**(V/m)	**Density** (kg/m^3)	**SAR**(W/kg)
Skin	1.25	17.982	1010	0.200
Skull	0.45	22.069	1810	0.060
Brain	1.29	6.96	1040	0.030

SAR value for different age group peoples

1)4years child

2)8years child

3) Adult, using computer simulation technology (CST)

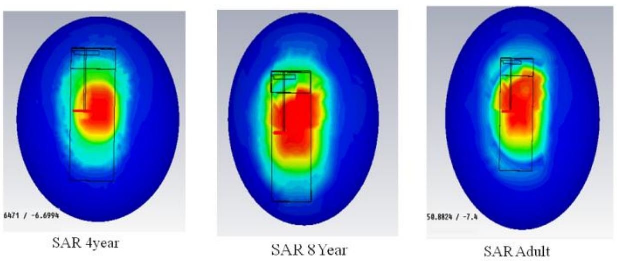

Fig.5.SAR values of different age group peoples

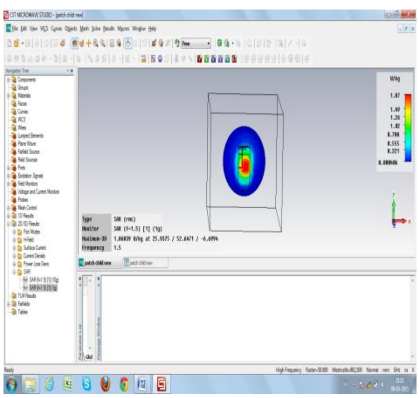

Fig.6. SAR- 4year child

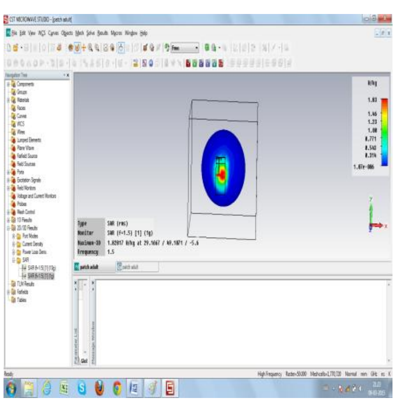

Fig.7. SAR -8year child

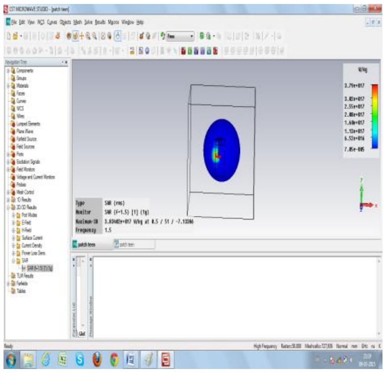

Fig.8. SAR-adult

Thermal Effects:

Thermal effects are due to rise in temperature produced by the energy absorbed from oscillating electric fields emitted by mobile phone antennas .The dark red color shows higher temperature near antenna feeding point and get varies along the length of the case. Similarly, the current generated in brain tissue which varies temperature. The power coupled causes the temperature to rise until, this induced heat reaches stable equilibrium value through blood circulation along the body which will take several minutes from the moment RF exposure occurs. Generally, thermal energy is dissipated from the body by sweating and increased peripheral circulation. The consequences of excessive heating in the body vary from temporary disturbances in cell functions to permanent destruction of tissues. The lens of eye may experience a temperature increase of 1°C at SAR level of 10 W/kg. At cell level the heating cause damage by disturbing the functioning of proteins. Cells begin to die when the temperature rises more than 5°C, but the tissues can endure momentary increase of tens of degrees shown in fig6,7,&8.

Thermal distribution for different age group peoples

1)4years child 2)8years child 3) Adult, using computer simulation technology (CST)

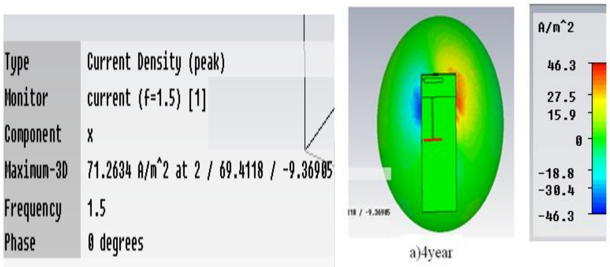

Fig9: 4YEAR CHILD

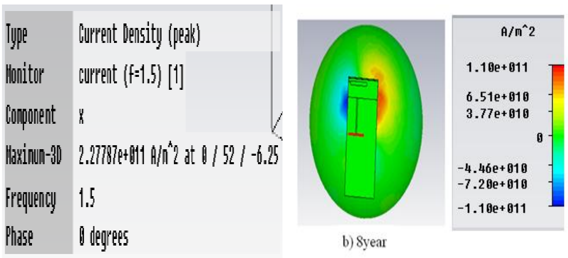

Fig10: 8YEAR CHILD

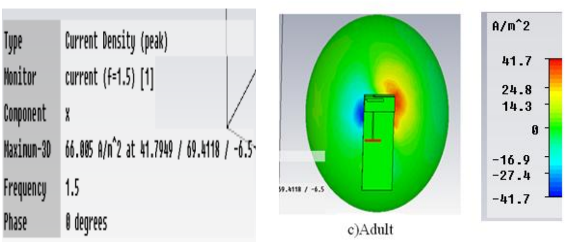

Fig11: ADULT

Computer simulation technology is used to generate animations of the electric surface currents with feeding port excited. Feeding port is used to generate power supply for patch antenna. Current distribution is different for 4 years child, 8 years child and adult, which depends upon the water content this, differs from people to people. The excitation of the port induces high-magnitude surface currents in the proximity of each feed, but a null-current area is clearly shown to exist at the open circuit end. The simulated S-parameter of the patch antenna is shown in above figure(9-11)

VIII. EXPERMENTAL RESULTS

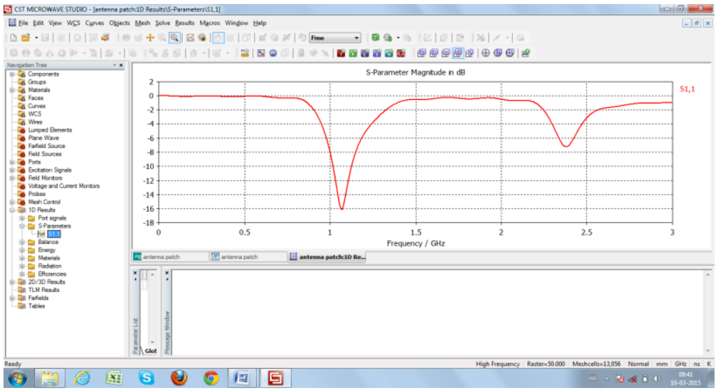

Figure: 12. S-parameters for patch antenna port [simulation results shows good return loss which suitable for mobile communication].

The result (Fig 12)indicates that, for frequency band of interest (0.5-3GHz), feeding port provides a better return loss suitable for wireless communication applications.The simulated 3-D gain pattern for patch antenna, for the operating frequency of 3GHz. The total efficiency of an antenna is defined as the ratio of total radiated power to the incident power at the feed. The original radiated pattern of patch antenna gets altered due to human head interaction shown in fig13,14..

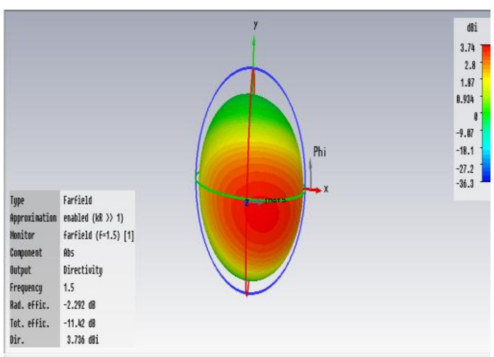

Figure13.Radiation pattern of patch antenna [simulated result of radiation pattern of patchantenna]

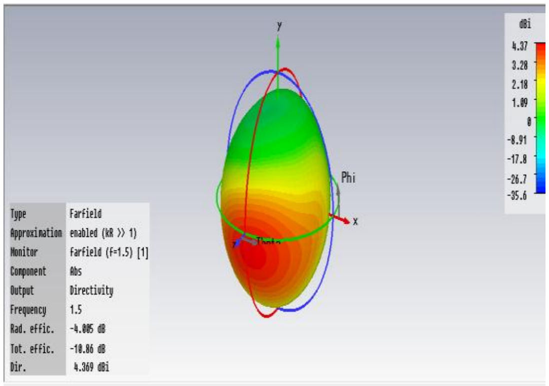

Figure: 14. Radiation pattern of patch antenna with human head interaction

IX. Mobile phone interaction with head modelSAR analysis

The spherical human head composed of three layers is simulated and is allowed to interact with the mobile phone placed very near to ear shown in fig 15.

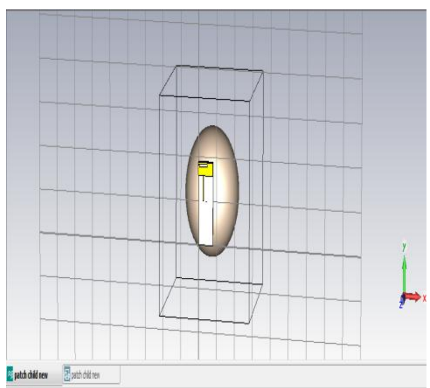

Fig.15. Mobile patch antenna interaction with head model

Table: 3.comparison of 1g and 10g tissue

Model	4years child	8years child	Adult
1g SAR(W/kg)	3.83402	1.8639	1.82617

10g SAR(W/kg)	0.89609	0.772787	0.742898

The value of SAR averaged over 1g and 10g tissues of human head have been computed, when mobile phone placed near human head and are listed in table3. The power absorption level of each layer differs due to its thickness, water content, conductivity and permittivity. Current distribution and 3D thermal distribution in head is shown in figure16-19.. From the results obtained using CST software, the SAR values are higher for children.

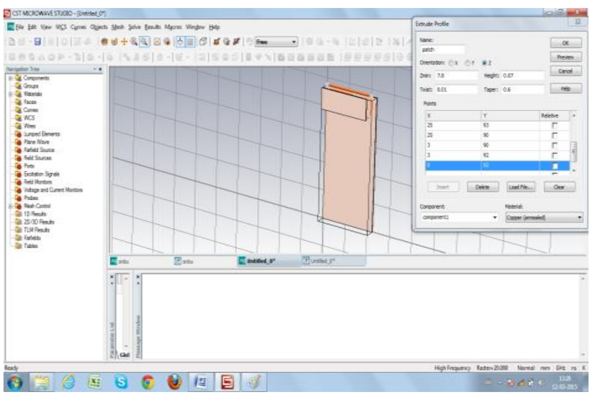

Fig: 16. Micro strip antenna with initial requirements

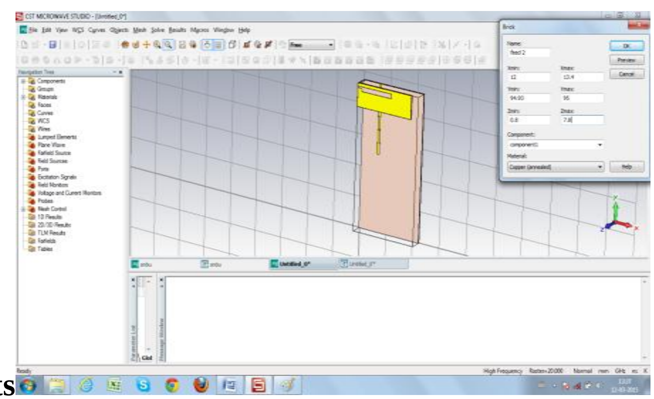

Fig: 17. Fully designed micro strip antenna

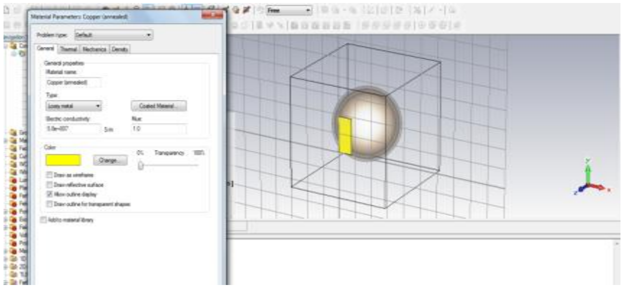

Fig: 18. Head model interaction with micro strip antenna

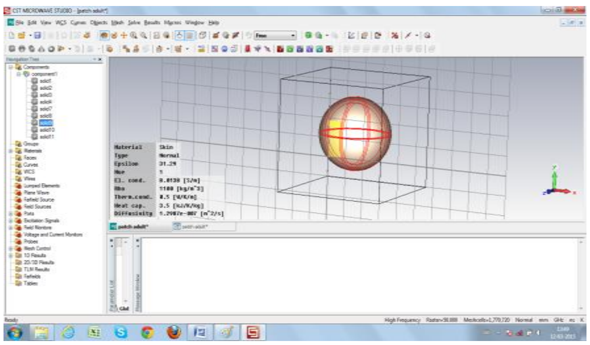

Fig: 19. Human head model with three layers

X. CONCLUSION

From the studies and above results, it is concluded that, the power absorbed by children head is higher than adult. It might be due to variation in the head tissue layer thickness, which is lower in case of children. Since, the skull bone of adult is very thick comparatively; the intensity of power coupled to the brain is lesser.The proposed system can be further developed to decrease its power coupled. The resistive sheet of 50ohm is placed on the user front side of mobile phone handset case. This method shows maximum of 50% decrement in the power coupled.

REFERENCES

[1] Aizat Azmi, Ahmad Amsyar Azman, Sallehuddin Ibrahim, and Mohd Amri Md Yunus, “Techniques In Advancing The Capabilities Of Various Nitrate Detection Methods: A Review”, International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 2, June 2017, pp. 223-261.

[2] Tsugunosuke Sakai, Haruya Tamaki, Yosuke Ota, Ryohei Egusa, Shigenori Inagaki, Fusako Kusunoki, Masanori Sugimoto, Hiroshi Mizoguchi, "Eda-Based Estimation Of Visual Attention By Observation Of Eye Blink Frequency", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 2, June 2017, pp. 296-307.

[3] Ismail Ben Abdallah, Yassine Bouteraa, and Chokri Rekik , "Design And Development Of 3d Printed Myoelctric Robotic Exoskeleton For Hand Rehabilitation", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 2, June 2017, pp. 341-366.

[4] S. H. Teay, C. Batunlu and A. Albarbar, "Smart Sensing System For Enhanceing The Reliability Of Power Electronic Devices Used In Wind Turbines", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 2, June 2017, pp. 407- 424

[5] SCihan Gercek, Djilali Kourtiche, Mustapha Nadi, Isabelle Magne, Pierre Schmitt, Martine Souques and Patrice Roth, "An In Vitro Cost-Effective Test Bench For Active Cardiac Implants, Reproducing Human Exposure To Electric Fields 50/60 Hz", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 1, March 2017, pp. 1- 17

[6] P. Visconti, P. Primiceri, R. de Fazio and A. Lay Ekuakille, "A Solar-Powered White Led-Based Uv-Vis Spectrophotometric System Managed By Pc For Air Pollution Detection In Faraway And Unfriendly Locations", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 1, March 2017, pp. 18- 49

[7] Samarendra Nath Sur, Rabindranath Bera and Bansibadan Maji, "Feedback Equalizer For Vehicular Channel", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 1, March 2017, pp. 50- 68

[8] Yen-Hong A. Chen, Kai-Jan Lin and Yu-Chu M. Li, "Assessment To Effectiveness Of The New Early Streamer Emission Lightning Protection System", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 1, March 2017, pp. 108- 123

[9] Iman Heidarpour Shahrezaei, Morteza Kazerooni and Mohsen Fallah, "A Total Quality Assessment Solution For Synthetic Aperture Radar Nlfm Waveform Generation And Evaluation In A Complex Random Media", International Journal on Smart Sensing and Intelligent Systems., VOL. 10, NO. 1, March 2017, pp. 174- 198

[10] P. Visconti ,R.Ferri, M.Pucciarelli and E.Venere, "Development And Characterization Of A Solar-Based Energy Harvesting And Power Management System For A Wsn Node Applied To

Optimized Goods Transport And Storage", International Journal on Smart Sensing and Intelligent Systems., VOL. 9, NO. 4, December 2016 , pp. 1637- 1667

[11] YoumeiSong,Jianbo Li, Chenglong Li, Fushu Wang, "Social Popularity Based Routing In Delay Tolerant Networks", International Journal on Smart Sensing and Intelligent Systems., VOL. 9, NO. 4, December 2016 , pp. 1687- 1709

[12] Seifeddine Ben Warrad and OlfaBoubaker, "Full Order Unknown Inputs Observer For Multiple Time-Delay Systems", International Journal on Smart Sensing and Intelligent Systems., VOL. 9, NO. 4, December 2016 , pp. 1750- 1775

[13] Rajesh, M., and J. M. Gnanasekar. "Path observation-based physical routing protocol for wireless ad hoc networks." International Journal of Wireless and Mobile Computing 11.3 (2016): 244-257.

[14]. Rajesh, M., and J. M. Gnanasekar. "Congestion control in heterogeneous wireless ad hoc network using FRCC." Australian Journal of Basic and Applied Sciences 9.7 (2015): 698-702.

[15]. Rajesh, M., and J. M. Gnanasekar. "GCCover Heterogeneous Wireless Ad hoc Networks." Journal of Chemical and Pharmaceutical Sciences (2015): 195-200.

[16]. Rajesh, M., and J. M. Gnanasekar. "CONGESTION CONTROL USING AODV PROTOCOL SCHEME FOR WIRELESS AD-HOC NETWORK." Advances in Computer Science and Engineering 16.1/2 (2016): 19.

[17]. Rajesh, M., and J. M. Gnanasekar. "An optimized congestion control and error management system for OCCEM." International Journal of Advanced Research in IT and Engineering 4.4 (2015): 1-10.

[18]. Rajesh, M., and J. M. Gnanasekar. "Constructing Well-Organized Wireless Sensor Networks with Low-Level Identification." World Engineering & Applied Sciences Journal 7.1 (2016).

[19] Aftab Ali Haider, AcmerNadeem, ShamailaAkram, "Safe Regression Test Suite Optimization: A Review",In: Proc. of IEEE International Conference on Open Source Systems and Technologies, pp. 7-12, 2016.

[20] AvinashGupta,Namita Mishra,Dharmender Singh Kushwaha, "Rule-Based test case Reduction Technique using Decision Table",In: Proc. of IEEE Conference on International Advance Computing Conference,pp.1398-1405,2014.

[21] Annibalepanichella,Rocco oliveto,Massimiliano Di Penta,Andrea De Lucia, “ Improving multi-objective test case Selection by Injecting Diversity in genetic Algorithms”, IEEE Transactions on Software Engineering,pp.358-383,Vol.41,No.4,April 2015.

[22] Zhang Hui, “Fault Localization Method Generated by Regression Test Cases on the Basis of Genetic Immune Algorithm”, In: proc. Of IEEE conference on Annual International Computers, Software & Applications Conference, pp. 46-51, 2016.

[23] S. Yoo and M. Harman, “Regression testing minimization, selectionand prioritization: A survey,” Softw. Test. Verif. Rel., vol. 22,no. 2, pp. 67–120, Mar. 2012.

[24] S. Yoo, “A novel mask-coding representation for set cover problemswith applications in test suite minimisation,” In: Proc. of 2nd International Symposium. Search-Based Software. Eng., 2010, pp. 19–28.

[25] S. Yoo and M. Harman, “Pareto efficient multi-objective test case selection,” In: Proc. of ACM /SIGSOFT Int. Symp. Softw. Testing Anal.,2007, pp. 140–150.

[26] S. Yoo and M. Harman, “Using hybrid algorithm for Pareto efficientmulti-objective test suite minimisation,” J. Syst. Softw.,vol. 83, no. 4, pp. 689–701, 2010.

[27] S. Yoo, M. Harman, and S. Ur, “Highly scalable multi objectivetest suite minimization using graphics cards,” In:Proc. of 3rd Int.Conf. Search Based Softw. Eng., 2011, pp. 219–236.

[28] Q. Zhang and Y.-W. Leung, “An orthogonal genetic algorithm for multimedia multicast routing,” IEEE Trans. Evol. Comput., vol. 3,no. 1, pp. 53–62, Apr. 1999.

[29] J. Zhu, G. Dai, and L. Mo, “A cluster-based orthogonal multi objective genetic algorithm”, Comput. Intell. Intell. Syst., vol. 51,pp. 45–55, 2009.

[30] E. Zitzler, D. Brockhoff, and L. Thiele, “The hypervolume indicatorrevisited: On the design of Pareto-compliant indicators via weighted integration”,In: Proc. of 4th Int. Conf. Evol. Multi-CriterionOptim., 2007, pp. 862–876.

[31] Jones JA, Harrold MJ. “Empirical Evaluation of the Tarantula Automatic Fault - Localization Technique”. In: Proc. of 20th IEEE/ ACM International Conference on Automated Software Engineering, 2005: 273-282.

[32] Jones JA, Harrold MJ, Stasko J. “Visualization of Test Information to Assist Fault Localization”.In: Proc. ofthe 24th International Conference on Software Engineering, 2002:467-477.

Abreu R, Zoeteweij P, ArjanJC, Gemund V. “On the Accuracy ofSpectrum-Based Fault Localization”. In:Proc. of Testing:Academic and Industrial Conference-Practiceand Research Techniques, 2007: 89-98.

Abreu R, ZoeteweijP, ArjanJC, GemundV. “An Evaluation of Similarity Coefficients for Software Fault Localization”. In: Proc. of the 12th Pacific Rim International Symposium on Dependable Computing, 2006: 39-46.

R. Pressman, 2010. Software Engineering: A practitioner’s Approach, 7th ed., McGraw Hill.

R. Binder, 2004. Testing Object Oriented Systems: Models, Patterns, and Tools, 5th ed., Addison Wesley.

Kadri, S. A New Proposed Technique to Improve Software Regression Testing Cost. International Journal of Security and Its Applications, 5, 3 (Jul. 2011).

A.A. Haider,.,Rafiq, S., Nadeem, A. 2012. Test suite optimization using fuzzy logic. In: Proc. of 8thInternational Conference on Emerging Technologies(Islamabad, Pakistan, Oct 2012). doi:10.1109/ICET.2012.6375440

A.A Haider, Nadeem, A. Rafiq, S. 2013. “On the fly Test Suite Optimization with Fuzzy Optimizer”. In:Proc. of Frontiers of Information Technology((Islamabad, Pakistan, Dec 2013).

A.A. Haider. A. Nadeem, S. Rafiq2014. “Multiple ObjectiveTest Suite Optimization: A Fuzzy Logic Based Approach”.Journal of Intelligent and Fuzzy Systems. 27, 2, 863-875.DOI: 10.3233/IFS-131045.

[2] D. White, A. Roschelle, P.Peterson, D.Schlicel, B.Biewald and W.Steinhurst, “The 2003 Blackout: Solutions that won’t Cost a Fortune”, The Electricity Journal, Elsevier Inc., November 2003, pp. 43-53.

[3] E. Leung, “Surge Protection for Power Grids”, IEEE Spectrum, July 1997, pp. 26-30.

[4] E. S. Ibrahim, “Electromagnetic Fault Current Limiter”, Electric Power System Research, Vol. 42, 1997, pp. 189-194.

[5] V.H.Tahiliani and J.W.Porter, “Fault Current Limiters – An Overview of EPRI Research”, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, no. 5, 1980, pp. 1964-1969.

[6] “Simple Current Limiter for DC 2770- Based Charger”, Maxim Application Note 2044, Dallas Semiconductor (ww.maxim-ic.com/an2044), 2003.

[7] “Flexible Hot-Swap Current Limiter Allows Thermal Protection”, Maxim Application Note 390, Dallas Semiconductor (ww.maxim-ic.com/an390), 2001.

[8] S.C.Mukhopadhyay, “Synthesis and Implementation of Magnetic Current Limiter”, Doctor of Engineering thesis, Faculty of Engineering, Kanazawa University, Japan, March 2000.

[9] S.C.Mukhopadhyay, M.Iwahara, S.Yamada and F.P.Dawson, " Analysis, design and experimental results for a passive current limiting device", IEE proceeding on Electric Power Applications, vol. 146, no. 3, pp. 309-316, May 1999.

[10] M.Iwahara, S.C.Mukhopadhyay, S.Yamada and F.P.Dawson, "Development of passive fault current limiter in parallel biasing mode", IEEE transc. on Magnetics, Vol. 35, No. 5, pp 3523-3525, September 1999.

[11] S.C.Mukhopadhyay, F.P.Dawson, M.Iwahara and S.Yamada, “A novel compact magnetic current limiter for three phase applications”, IEEE transc. on Magnetics, Vol. 36, No. 5, pp. 3568-3570, September 2000.

[12] P. Malkin and D. Klaus, “Cap That Current”, IEE Review, March 2001, pp. 41-45.

[13] W.Paul, et.al., “Test of 1.2 MVA high-Tc superconducting fault current limiter”, Proc. On Superconducting Sci. Technol., IOP Publishing Ltd., 10 (1997), 914-918.

[14] G.E.Marsh and A.M.Wolsky, “AC losses in high-temperature superconductors and the importance of these losses to the future use of HTS in the power sector”, Report submitted to International Energy Agency, USA, May 2000.

[15] M. Steurer, H. Brechna and K. Frohlich, “A Nitrogen Gas Cooled, Hybrid High Temperature Superconducting Fault Current Limiter”, IEEE Transactions on Applied Superconductivity, vol. 10, No. 1, 2000, pp. 840-844.

[16] T. Ohnishi, N. Aizawa, A.Yamagata, A. Nii and M.Shibuya, “Stability of a Shorted Nb3n Coil Cooled by a Refrigeration for a Magnetic Shield Type Fault Current Limiter”, IEEE Transactions on Applied Superconductivity, vol. 10, No. 1, 2000, pp. 845-848.

[17] V. Keilin, I. Kovalev, S.Kruglov, V.Stepanov, I.Shugaev and V.Shcherbakov, "Model of HTS Three-Phase Saturated Core Fault Current Limiter", IEEE Transactions on Applied Superconductivity, vol. 10, No. 1, 2000, pp. 836-839.

[18] S.C.Mukhopadhyay, C.Goonaratne, M.Staines, I.Vajda, M.Iwahara and S.Yamada, "Feasibility study of developing high temperature superconducting fault current limiter: A New Zealand perspective", Proc. *ISEM 2003*, pp. 100-101, France, May 12-14, 2003.

[19] S.C.Mukhopadhyay, C. Gooneratne and M. Staines, "Transition of magnetic current limiter to superconducting fault current limiter", Proceeding of AUPEC conference, paper no. 3, Sep. 28- Oct. 1, 2003, Christchurch, New Zealand.