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Full Length Research Paper

New low specific absorption rate (SAR) antenna design for mobile handset

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We intend and design a new type of mobile handset antenna structure to reduce the specific absorption rate (SAR) in human head. The designed of low SAR handset antenna will be operating at 2.4 GHz frequency for wireless local area network (WLAN) by considering some parameters that determine the performance of the antenna. The authors carried out simulation by placing antenna at different position to determine position that are more suitable and effectively reduced the SAR level. The numerical results are compared and analyzed. The designed antenna operating at the range of frequency from 2373 to 2435 MHz with 2.6% bandwidth (BW) and the radiation pattern is omni-directional. The handset antenna design has achieved 1.483 W/kg for 1 gm SAR and 1.192 W/kg for 10 gm SAR which has been reduced for about 25.75% for 1 gm and 25.50% for 10 gm SAR value of the standard SAR level.

Key words: Finite-difference time-domain (FDTD) method, patch antenna, specific absorption rate (SAR), symmetry.

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. These behaviors are motivated by two factors: the need to evaluate the antenna performance in the presence of a human body, and the need to evaluate the rate of radio frequency (RF) energy declaration in the biological tissue, called specific absorption rates (SAR), in order to assess possible health effects and compliance with various RF exposure standards. Recently, the design of mobile handset antennas begins to move away from an omnidirectional type to a selective directivity type or a low SAR type. This is driven mostly by public concerns of potential health hazards of RF radiation into a user's head (Jensen and Rahmat-samii, 1995; Hombach et al., 1996; Islam et al., 2009; Faruque et al., 2010a).

The interaction of the cellular handset with the human head has been explored by many published papers considering; first, the effect of the human head on the handset antenna performance including the feed-point impedance, gain, and efficiency (Kouveliotis et al., 2006; Sulonen and Vainikainen, 2003; Krogerus et al., 2005; Faruque et al., 2010b; Misran et al., 2011), and second, the impact of the antenna electromagnetic (EM) radiation on the user's head due to the absorbed power, which is measured by predicting the induced SAR in the head tissue (Islam et al., 2010; Faruque et al., 2011a, Misran et al., 2011). Antenna performance can be optimized or evaluated through radiation pattern, return loss, voltage standing wave ratio (VSWR), gain, polarization, path loss, multipath, interference, polarization distortion, effects of earth and surroundings, antenna cost, antenna size and appearance. The above stated parameters and issues are equally important and were taken into consideration during the design process of an antenna. So an antenna type needs to be appropriate to the specifications that need to follow to design antenna (Wong, 2003; Faruque et al., 2011b).

The antenna size constraints imposed by mobile handset requirements and the availability of new dielectric materials has created much interest in dielectric loaded antennas (Bit-Babik et al., 2004; Wong et al., 2005).

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Tuning stability and good isolation from the handset and the human operator are cited as important features of dielectric loading which may enable a stand-alone ceramic chip antenna to be finally realized in practice over all the operating bands. There are also some expectation that somewhat less power is dissipated in the operator's head but the orientation of the dielectric antenna with respect to the head and the position of the antenna inside the handset in relation to the electronics are likely to remain the major influence on SAR. SAR is influenced by many parameters and it was handled and took into consideration three parameters to reduce the SAR level. Substrate permittivity, position of the antenna, type and size of the antenna are those factors that reduced the SAR level of this antenna (Islam et al., 2009; Faruque et al., 2011c).

The utility of ferrite as loading material has previously been investigated (James and Henderson, 1978) but recently the merits of equalizing the material relative permittivity and permeability values have been reported (James and Vardaxoglou, 2002; Vardaxoglou et al., 2003; Kitra et al., 2003). The benefits include increased bandwidth (BW) and radiation efficiency (η). The manipulate of magnetic material on dielectric resonator antennas has also been investigated (James et al., 2004). A previous study (Islam et al., 2009) used a ferrite sheet attachment on the handset case to reduce SAR. Realizing ferrite material, as a metal material has been considered (Buell et al., 2004; Islam et al., 2010). However, for handset compacted antenna applications, the metal material heterogeneity and obtaining a small enough cell size are apparent difficulties with this concept.

The development of wireless local area networks (WLAN) at home and work has also necessitated the demand for antennas that are compact and inexpensive. Wire antennas, such as whips and helical antennas are sensitive to only one polarization direction. As a result, they are not optimal for use in portable communication devices which require robust communications even if the device is oriented such that the antenna is not aligned with a dominant polarization mode (Wong, 2003).

The protocol and procedures for the measurement of the peak spatial-average SAR induced inside a simplified head model of the cellular handset users are specified by institute of electrical and electronics engineers (IEEE) standard-1528 (IEEE Standard-1528, 2005) and international electrotechnical commission (IEC) 62209-1 (IEC 62209-1, 2005). Anatomically, correct head models of a non homogeneous human head at different ages were used to evaluate the performance of the handset on a human head phantom (Beard et al., 2006; Wang et al., 2006).

This paper proposed that the above established material loading techniques were brought together to create a multiband low SAR handset antenna. The continued reduction in the SAR is of interest to both manufacturers and users and is the central theme in our paper. This paper commences with the analysis of generic spherical shaped loaded monopoles and their extension to more realistic shapes. Optimal BW, radiation efficiency and SAR properties are demonstrated by simulation using Flomerics' microstripes transmission line matrix (TLM) method and measurements. In particular, the influence of the choice of materials and the antenna excitation process on the near-fields and hence SAR, are considered. Retention of the antenna performance when embedded in a typical handset ground plane has received much attention in the present research, and simulated results are included making available many design options to achieve the multiband low SAR operation.

NUMERICAL METHOD FOR ANTENNA DESIGN

The handset and the specific anthropomorphic mannequin (SAM) phantom head is considered for this simulation study that is provided by computer simulation technology microwave studio (CST MWS). The microstrip patch antenna is included in the simulation model. A complete handset model composed of the circuit board, liquid crystal display (LCD) display, keypad, battery, and housing was used for simulation. The SAR was simulated using a homogeneous spherical phantom of radius 75 mm. It has been established (Meier et al., 1997; Khalabatri et al., 2006; Kim and Rahmat-Samii, 1998) that the use of a homogeneous spherical phantom gives worse-case simulation of the peak 10 gm SAR compared to an anatomically accurate heterogeneous phantom head. Computations times are also much less for the former. The phantom material parameters chosen were conductivity and density which resemble human tissue.

The antenna radiating power external to the antenna was normalized at 125 mW. In all the simulations in this paper, the sphere surface was placed 15 mm distant from the antenna surface of interest.

Basically, all patch antennas has common feature which consist of four elements. Those four elements are:

- A very thin flat metallic region often called the patch
- A dielectric substrate
- A ground plane, which is usually much larger than the patch
- A feed, which supplies the element radio frequency (RF) power.

Microstrip elements are often constructed by etching the patch and sometimes the feeding circuitry from a single printed-circuit board clad with conductor on both of sides.

The length of the patch (L) is typically about a third to a half of a free-space wavelength λ_0, while the dielectric thickness is in the range of $0.003\lambda_0$ to $0.5\lambda_0$. A commonly used dielectric for such antennas is polytetrafluoral ethylene (PTFE), which has a relative dielectric constant of about 2.5. Sometimes, a low-density cellular material is used to support the patch. This material has a relative dielectric constant near unity and usually results in an element with better efficiency and larger bandwidth but at the expense of an increase in element size. Substrate materials with high dielectric constants can also be used. Such substrates result in elements that are electrically small in terms of free-space wavelengths and consequently have relatively small bandwidth and low efficiency. Figure 1 shows the proposed low SAR patch antenna elements typical structure and side view of rectangular patch antenna shown in Figure 2. Also Figures 3 and 4 can be seen to show the build on patch antenna feed arrangement and how to develop on feed antenna arrangement. The geometric configuration of proposed antenna is shown in Table 1.

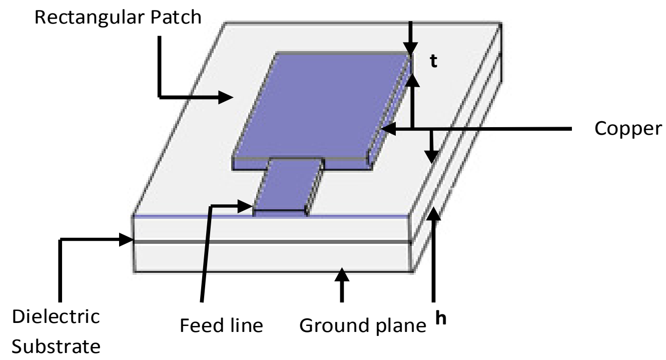

Figure 1. A typical rectangular patch antenna element.

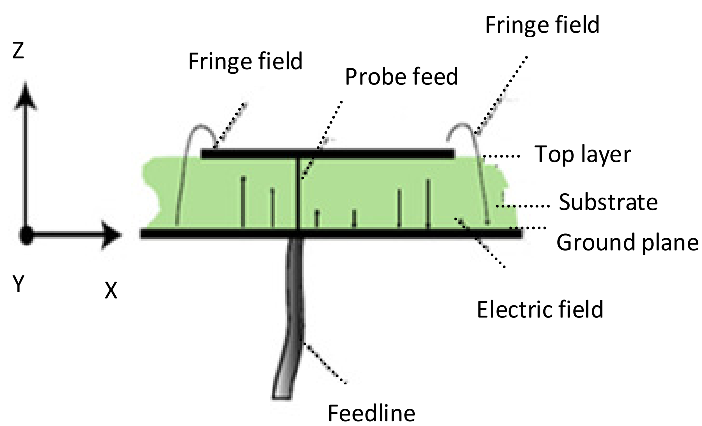

Figure 2. Side view of rectangular patch antenna.

The substrate chosen for this project is Roger 4003 (hydrocarbon Ceramic) which has dielectric constant, ε =3.38, and loss tangent 0.0022. The dielectric constant preferred to be less than 2.5 or otherwise smaller size patch is desired.

SPECIFIC ABSORPTION RATE (SAR)

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). The value cited is then the maximum level measured in the body part studied over the stated volume or mass. SAR can be calculated from the electric field within the tissue as:

$$SAR = \frac{\sigma}{2\rho} E^2 .$$

where σ is sample electrical conductivity; *E*, RMS electric field, and P, sample density.

The root mean square (rms) value of the electric field strength in the x, y, z point, E is defined by:

$$E = (E_x^2 + E_y^2 + E_z^2)^{\frac{1}{2}} \qquad (1)$$

where the E_x, E_y and E_z are the rms values of the x, y, and z components of the electric field.

RF electrical currents in the antenna and in the casing of a handheld mobile phone will induce RF electric fields in tissue. As a result of this, a part of the radiated energy will be absorbed into tissue causing an increase in the tissue temperature. The absorption is caused by the power loss involved with dielectric molecules polarization. Vibrations of water molecules, movements of free ions and movements of bound charges attached to macro-contribute most to the dielectric polarization in biological material in radio frequencies.

SAR is used to measure exposure to fields between 100 kHz and 10 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. Thus tests must be made with each specific source, such as a mobile phone model, and at the intended position of use. For example, when measuring the SAR due to a mobile phone, the phone is placed at the 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. Various governments have defined safety limits for exposure to RF energy produced by mobile devices that mainly exposes the head or a limb for the RF energy: The designers of handset antenna are simulated in cheek mode and data mode to investigate the effect of the proposed structure to the antenna performance in the vicinity of

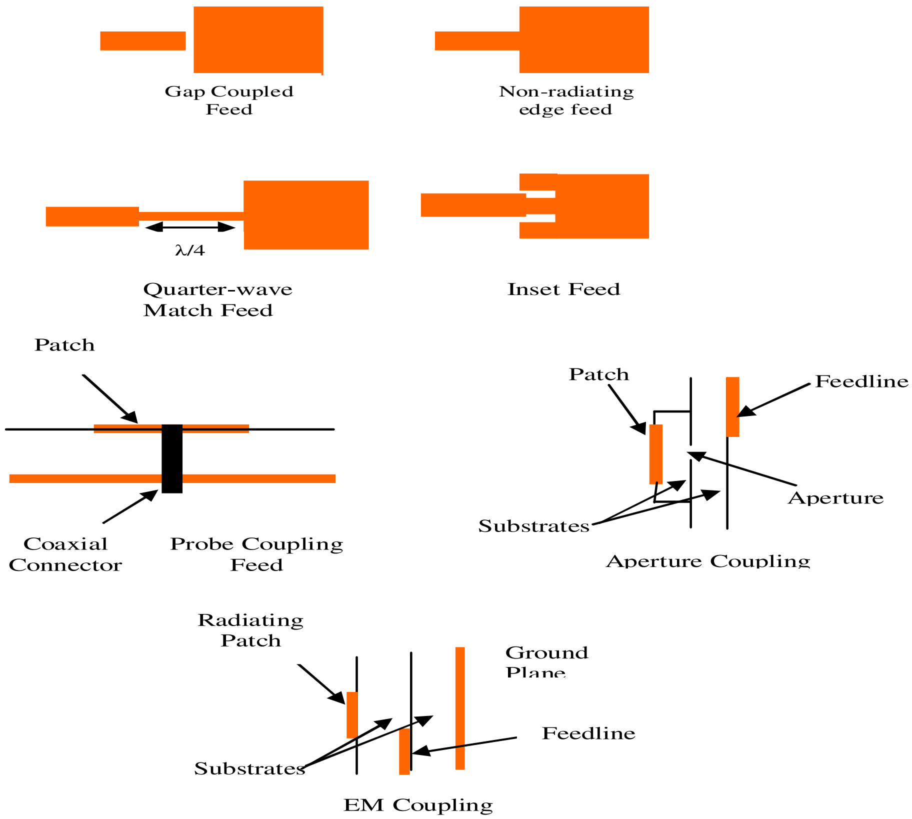

Figure 3. Patch antenna feed arrangements.

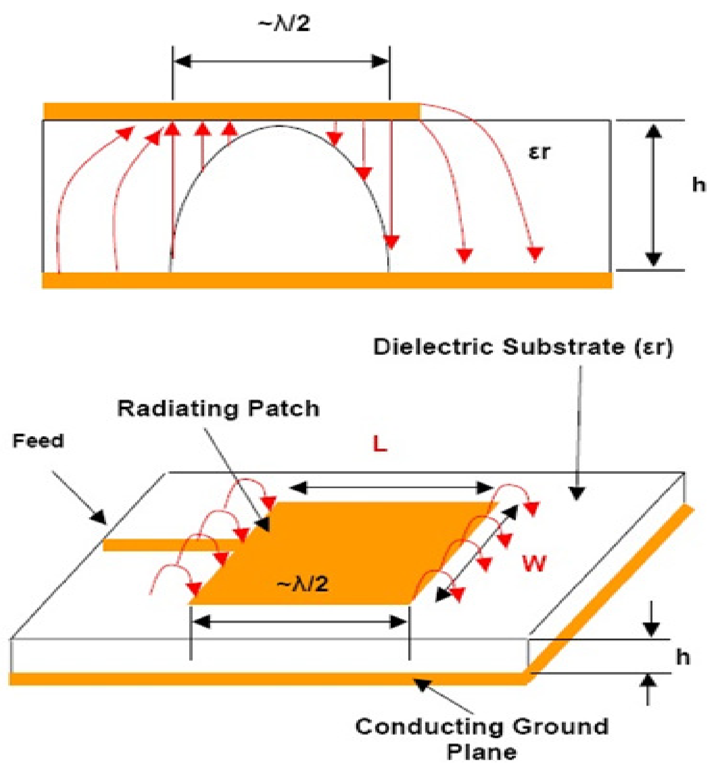

Figure 4. Rectangular patch antenna electric field pattern.

Table 1. Antenna specifications.

Specification	
Width	39.5 mm
Length	31.5 mm
Thickness	1.524 mm
Substrate	Rogers 4003
Ground plane	PEC
Operating frequency	2.4 GHz
Probe feed coordinate	(0, 9)

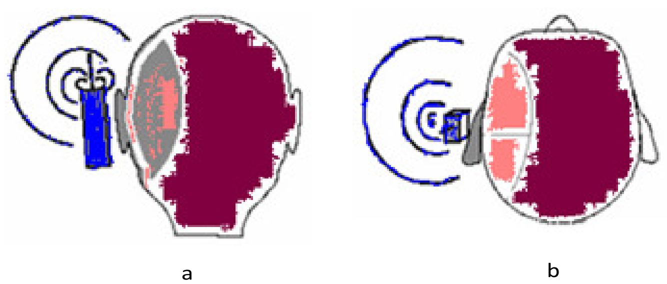

Figure 5. Head model with handset antenna for SAR calculation: a, Cheek mode; b, data mode position.

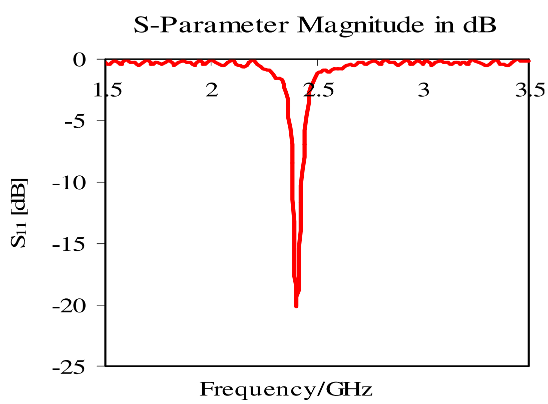

Figure 6. Simulated return loss of new designed patch antenna.

human head. In the cheek mode, the chassis of the antenna fully touches the cheek of the head model and data mode is also some angle touches distance of the head model. The antenna-head position in this mode is shown in Figure 5.

RESULTS AND DISCUSSION

The handset antenna design and the development process of the patch antenna and specific absorption rate level, the results for the simulations by using CSTMWS can now be presented and discussed. Antenna designs was simulated and optimized over and over again until satisfactory results are obtained. Based on these results, discussions will be made on the specific absorption rate level and performance of the antenna. The accomplished results such as return loss curves and radiation patterns and SAR level for designed antenna will be discussed. In addition, analysis of the results of the designed patch antenna will be made to find out if it fulfills the basic criteria for operation in the proposed wireless communication networks or systems with lower SAR level.

A return loss plot indicates how well the link and channel's impedance matches its rated impedance over a range of frequencies. High return loss values mean a close impedance match, which results in greater differentiation between the powers of transmitted and reflected signals.

As can be seen in Figure 6, the resonant frequency of the antenna is 2400 MHz. The return loss of the antenna is -19.53 dB at 2400 MHz for VSWR of 2 as shown in Figure 6. The simulated results show that, the antenna covering the frequency ranges from 2373 to 2435 MHz. Antenna has 2.6% (62 MHz) BW which is suitable for WLAN applications. Even though the designed antenna gave a much narrower BW but it is applicable for WLAN applications which are operating at centre frequency of 2400 MHz. The antenna can be modifying to give a better return loss at 10 dB and at 14 dB by optimizing the slots to excite at a closer resonance frequency without sacrificing the BW requirement of the WLAN band.

While consideration of the antenna performance in terms of efficiency by analyzing returns losses, there is another main property that must be analyzed when considering the viability of the antenna, which is the radiation pattern. The radiation pattern of the antenna which is operating at 2400 MHz is shown below in 3D pattern view as shown in Figure 7a to c and 2D pattern view Is shown in Figure 7d.

Based on the graph and pictures above, the gain of antenna influence by the dominant E-Theta field is vertical polarization. The radiation pattern is omni-directional which is perfectly suitable for WLAN. Even though it is an omnidirectional radiation pattern but the radiation is not fully occupied by the 360° region in far field radiation pattern. There was a very slight drop in the electric field strength in direction of the two ends of the antenna.

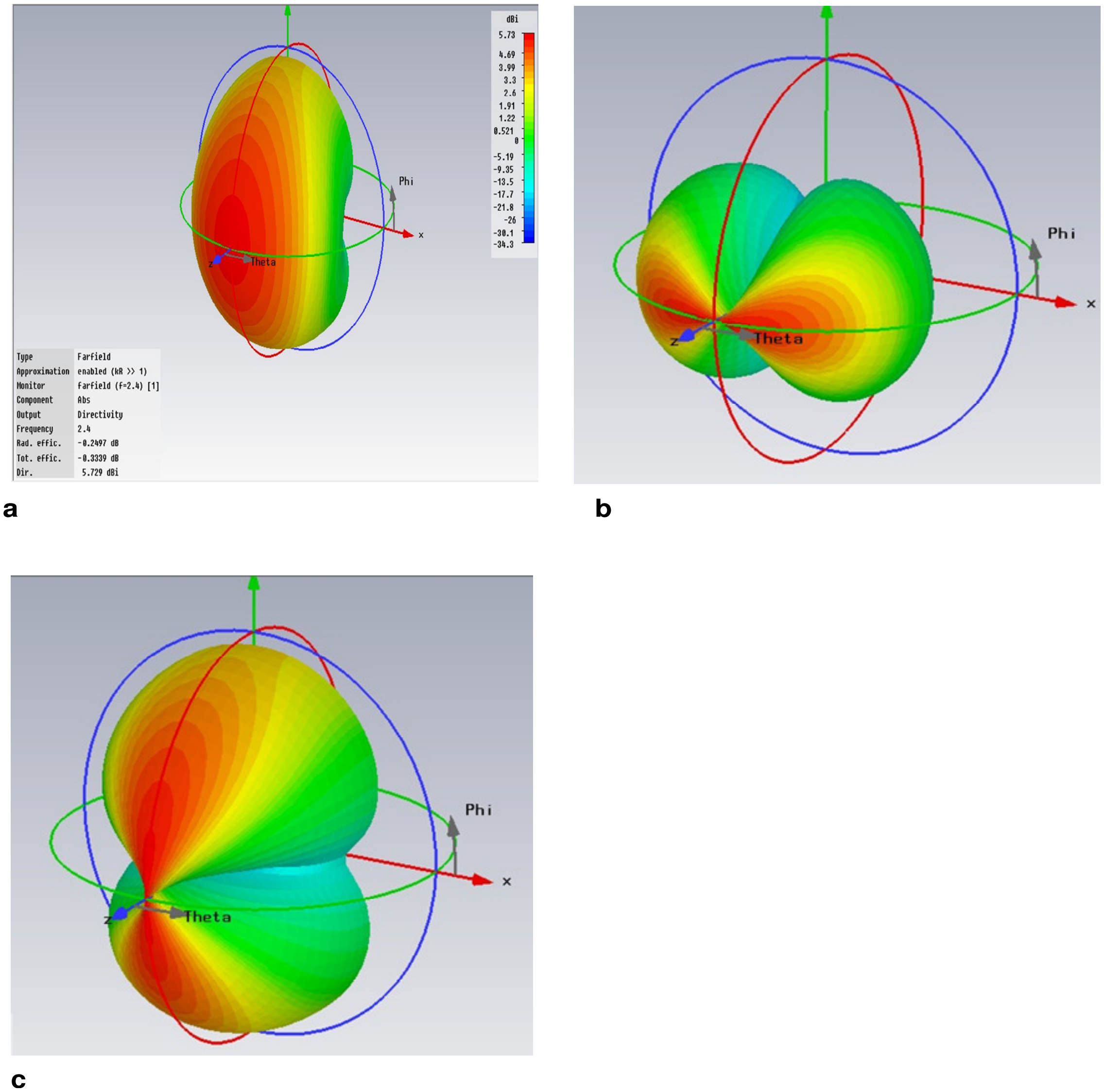

Figure 7. a, Overall far field radiation pattern for proposed handset antenna; **b,** phi view of far field radiation pattern for proposed handset antenna; **c,** theta view of far field radiation pattern for proposed handset antenna.

Reduction of SAR with proposed handset antenna investigation

Microstrip patch antenna incorporated for the mobile handset is very perceptive in their resulting SAR averages when alterations to the structures are incorporated. It is seen that undemanding changes to the handset model can result in large improvements in the SAR performance.

A fundamental handset antenna design has been modelled. Alterations have then been made and comparative results taken. The fundamental design used means that the SAR averages will be inclined to be over-estimations. This allows us to simulate easier models whilst retaining essential information concerning the radiating characteristics of the structures. The handsets have been modelled using the advanced mobile phone system (AMPS) phone system. These handsets use the highest average power of 600 mW incessantly, implying that any advantage found under the AMPS system will be displayed in other handset systems which operate under an inferior average power.

In the beginning, two sets of results were considered, one set employing a λ/4 monopole, the other employing a patch antenna both operating at 900 MHz. If we first of all consider the monopole investigation, a starting SAR value of 6.82 Wkg was recorded over a mass of 1 g and 4.32 W/kg for SAR 10 g. Concern was initially raised over such a high value until another study by Okoniewski and Stuchly (1996), was consulted which also recorded similarly high values. The study proves that, depending on the model used, high SAR averages are simply

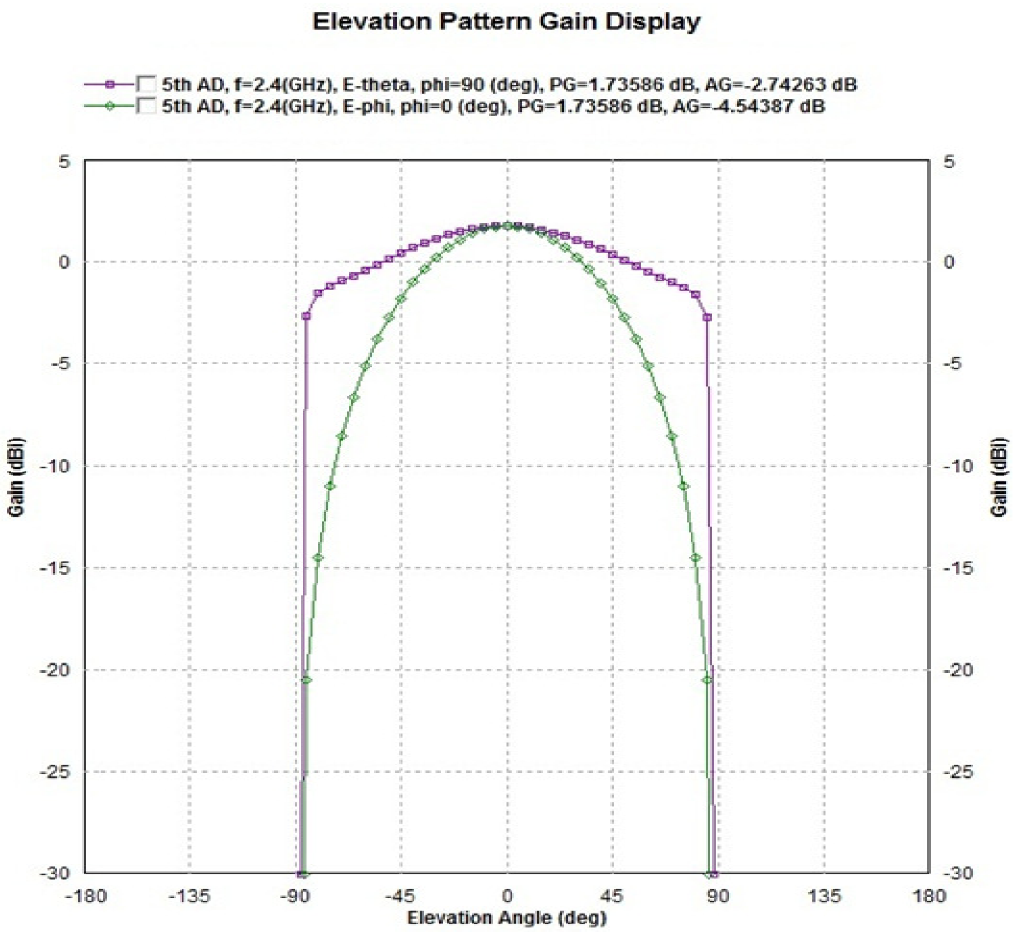

Figure 7d. 2D view of far field radiation pattern for proposed handset antenna.

available for handsets operating with an average power of 600 mW. These comprise removing the ear, alterations to the protecting can and to the electrical bone parameters. A decrease of 0.87 W/kg was recorded when the ear was removed. This might be seen to be a surprising result given the nearness of the antenna to the brain tissue. Enlightenment to the decrease sheet is given if the averaging process is considered. When placed next to the ear, the radiation is localized in one region, the ear. When the ear is removed, the radiation is distributed over a larger area, and thus the average over a mass of 1 g decreases. This is established by the l0 g average which has gone up from 2.29 W/kg to 3.98 W/kg, indicating that the radiation has been circulated over a larger area than before. The most considerable reduction in SAR is seen when a plane of the protecting sheet is removed, as in the new simulation. The SAR average over 1 g has decreased by more than 57.75% for SAR 10 gm (Islam et al., 2009), suggesting that the shielding sheet and its location relative to the head has a noteworthy persuade on the resulting SAR. One more important result is the new simulation in which the electrical parameters of bone have been altered. Electrical parameters of bone are difficult to measure and this is reflected in the differing values used in research studies. The effect of an alteration to the electrical parameters has been simulated in a change of permittivity from 6.4 to 13.6 and the conductivity from 0.10 to 0.14 at 900 MHz. These changes record a decrease in SAR of 0.48 W/kg over 1 g from the previous simulation. The finishing simulation in which an air gap has been built-in all around the protecting can produces a slightly unexpected SAR result as it records an increase over 1 g. This implies that the radiating formation has been changed, indicating that the internal makeup of the handset is also significant in the thoughtfulness of SAR.

The investigation into a patch antenna element is summarized in Table 2. The element is modelled on the back of the handset, towards the top of the shielding materials. The results indicate that the main consideration here is the position of the feed on the element. If the feed is located on the side of the handset or at the bottom of the element, significant increases in SAR are seen. If the feed is placed at the top of the handset then it allows more radiation to escape over the head rather than be absorbed by it. It must also be noted that the results of

Table 2. Patch antenna with handset SAR simulation results at 900 MHz (P_R=600 mW).

Simulation result	1 gm SAR	10 gm SAR
Patch starting geometry	1.274	0.873
Patch oriented vertically	1.192	0.827
Patch wrapped ground side of handset, feed on side	1.785	1.231
Patch starting geometry, feed at bottom of antenna	1.693	1.183

Table 3. SAR results for different lengths of antenna at 900 MHz (P_R=600 mW).

Antenna name and position		Length	SAR 1 g	SAR 10 g
Monopole	C	25	4.98	2.23
	T	25	2.99	1.82
Patch	C	50	4.67	1.93
	T	50	2.61	1.82
Patch	C	80	4.13	1.74
	T	80	1.90	1.28
Patch	C	100	3.56	1.34
	T	100	1.66	1.19

Table 4. Thickness of the substrate with SAR value.

	Thickness, h (mm)			
Value of SAR (W/kg)	1.5	2.0	2.5	3.0
SAR 1 gm	1.483	1.908	2.979	3.812
SAR 10 gm	1.192	1.602	2.456	3.536

the patch are all significantly lower than the corresponding monopole antenna results. The handset geometry used has remained the same for both elements, indicating that a back mounted solution does result in a reduced SAR.

A number of recommendations can be highlighted as a result of the reduced SAR investigation. The results given by the patch indicate that the increased distance between the radiating element and the head can significantly reduce the average SAR. The appearance and performance and public acceptance of such elements however also need to be taken into consideration. As mentioned earlier, the size of antenna has influence on the reduction of SAR value, so the size of antenna was varied to analyze the size effect. The main dimensions are the thickness, width and length. In this case, the thickness of the antenna was adjusted according to the SAR reductions effectiveness and also according to the dimension of the cellular phone model, so that antenna fit on the phone case.

The substrate has many influences in designing an efficient antenna. The thicker substrate is mechanically strong, increase the radiated power, reduce conductor loss and improve impedance bandwidth. The disadvantages of thicker substrate are increase dielectric loss, increase weight, increase surface wave loss and extraneous radiations from the probe feed which will increase the SAR level.

The width and length of the antenna was maintained at constant value and varied the thickness value to identify the effectiveness of thickness on SAR reduction. The width and length value is smaller than the calculated value to make it fit into the phone case and to improve the performance of antenna.

Another way of introducing spacing between the antenna and head is to include profiling at the front of the handset. This can be incorporated into the design of the handset so that it is aesthetically pleasing whilst still reducing the SAR. The length of the antenna at 900 MHz can also have a significant effect on the resulting SAR. Table 3 gives results taken for different length of the antenna. These results clearly indicate that longer antennas result in low SAR.

Table 4 shows that SAR value in the thickness of

Table 5. Effects of attaching locations of antenna on SAR reduction at 2.4 GHz.

Parameter	Category 1	Category 2	Category 3
SAR 1 gm (W/kg)	2.058	1.483	1.608
SAR 10 gm (W/kg)	1.708	1.192	1.299

substrate 2 to 3.5 mm varied. The reduction efficiency of the SAR depends on its thickness of substrate. In Table 4, it is shown that if the thickness of the substrate is varied SAR value also increases. As shown in Table 4, the thickness is considered 1.5 mm at that time this value is acceptable after that when considered the thickness of 2.0 mm, the SAR value for 10 gm is acceptable but the SAR value for 1 gm overcome the SAR limit. Substrate which has thickness greater than 2 mm exceeds the SAR limit for both 1 gm and 10 gm of SAR.

This fact also needs to be analyzed before designing a low specific antenna for WLAN. To analyze this factor, initially a standard size phone case was created to place antenna at different places. The phone case with length 100 mm, width is 40 mm and the height of 18 mm phone case is created. The position of the antenna has a great influence in SAR reduction. Antenna which is close to the head has higher SAR value compared to the antenna far away from head which is placed at backside of phone case and at the bottom of the phone case.

After analyzed parameters that have persuaded in reduction of SAR of antenna, now by using those methods, the antenna was designed to get low SAR value. The antenna was designed by using Roger 4003 loss free substrate and with appropriate size especially by reducing the thickness of substrate. So in the following, the numerical results and discussions are limited to category 2. Since the antenna is an EM absorptive one, the attaching positions and size of antenna may be an important factor for the reduction of EM absorption as shown in Table 5.

Finally, the antenna was simulated at 2.4 GHz frequency by selecting E-field, H-field, power flow, current density, power loss density (SAR), electric energy density, magnetic energy density and far field. After the simulation was completed, the SAR value was calculated for both 1 and 10 gm of tissue sample. By using these methods, the SAR value for the antenna which is operating at 2.4 GHz was successfully reduced.

To end with, substrate, size (especially length of the height), and position of the antenna have influence in reducing SAR of an antenna. Even though, all three methods decreased the SAR level but substrate thickness and length of the antenna is the most influential factor in reducing SAR of antenna. When the thickness of the substrate increases, there is drastic increase in SAR value too compared to the placement of the antenna inside the phone case. Although, the antenna placed far away from head inside phone case, the SAR values just decrease in small value. When the thickness of the substrate increases, it will emit extraneous radiation from probe feed which increase the SAR.

Conclusion

The low SAR antenna was effectively designed by using appropriate methods. The factors that persuade the SAR were analyzed and by considering those factors, the SAR level of the antenna was reduced. The designed antenna also operated at 2.4 GHz frequency and had an omni directional radiation pattern. In addition, this antenna is suitable for WLAN applications. Parameters such as the amount of shielding sheet, feed position, and electrical parameters of tissues may all have significant effects on the resulting SAR. Also, increased distance between the radiating element and head can significantly reduce SAR. As a result, by implementing these simple and easy methods, the SAR of an antenna can be reduced and it possibly could be implementing to the mobile devices in the market. It is established that the novel design of the low SAR antenna does not degrade its RF performance though has a great improvement of reducing the SAR level inside the user’s head.

Abbreviations: SAR, Specific absorption rate; **WLAN**, wireless local area network; **RF**, radio frequency; **EM**, electromagnetic; **VSWR**, voltage standing wave ratio; **BW**, bandwidth; **IEEE**, institute of electrical and electronics engineers; **IEC**, international electrotechnical commission; **TLM**, transmission line matrix; **CST MWS**, computer simulation technology microwave studio; **LCD**, liquid crystal display; **PTFE**, polytetrafluoral ethylene; **rms**, root mean square; **MRI**, magnetic resonance imaging; **AMPS**, advanced mobile phone system; **FDTD**, finite-difference time-domain; **SAM**, specific anthropomorphic mannequin.

REFERENCES

Bit-Babik G, Nallo DC, Faraone A (2004). Multimode dielectric resonator antenna of very high permittivity. IEEE Int. Conf. Antennas. Propagation, pp. 1383-1386.

Beard BB, Kainz W, Onishi T (2006). Comparisons of computed mobile phone induced SAR in the SAM phantom to that in anatomically correct model of the human head. IEEE Trans. Electromagn. Compatibility, 48(2): 397-407.

Buell K, Mosallaei H, Sarabandi K, (2004). Embedded circuit magnetic metamaterial substrate performance for patch antennas. Proc. IEEE APS, pp. 1415-1418.

Faruque MRI, Islam MT, Misran N (2010a). Effect of human head shapes for mobile phone exposure on electromagnetic absorption. Informacije MIDEM, 40(3): 232-237.

Faruque MRI, Islam MT, Misran N (2010b). Evaluation of specific absorption rate (SAR) reduction for PIFA antenna using metamaterials. Frequenz J., 64(7/8): 144-149.

Faruque MRI, Islam MT, Misran N (2011a). Analysis of Electromagnetic Absorption in the Mobile Phones Using Metamaterials. Electromagnetics J., 31(3): 215-232.

Faruque MRI, Islam MT, Misran N (2011b). Electromagnetic (EM) Absorption Reduction in a Muscle Cube with Metamaterial Attachment. Med. Eng. Phys, 33(5): 646-652.

Faruque MRI, Misran N, Nordin R, Islam MT, Yatim B (2011c). Estimation of Specific Absorption Rate (SAR) and Temperature Increases in the Human Head of Portable Telephones. Sci. Res.Essays, 6(6): 1209-1215.

Hombach V, Meier K, Burkhardt M, Kuhn E, Kuster N (1996). The dependence of EM energy absorption upon human head modeling at 900 MHz. IEEE Trans. Micro. Theory Tech., 44: 1865-1873.

IEC 62209-1 (2005). Human exposure to RF fields from hand-held and body mounted wireless communication devices-human models, Instrumentation and procedures- Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (Frequency range of 300 MHz to 3 GHz). 215 p.

IEEE Standard-1528 (2005). Recommended practice for determining the peak spatial-average specific absorption rate (SAR) in the human head from wireless communications devices-measurement techniques.

Islam MT, Faruque MRI, Misran N (2009). Design analysis of ferrite sheet attachment for SAR reduction in Human head. Prog. Electromagn. Res, pp. 98: 191-205.

Islam MT, Faruque MRI, Misran N (2010). Study of specific absorption rate (SAR) in the human head by metamaterial attachment. IEICE Electronics Express, 7 (4): 240-246.

James JR, Chair R, Luk KM, Chow KM, Leung KW, Vardaxoglou JC (2004). Influence of magnetic material on dielectric resonator antenna excitation. Proc. Inst. Elect. Eng. Microwave Antennas Propagation, 151(4): 293-298.

James JR, Henderson A (1978). Electrically short monopole antennas with dielectric or ferrite coatings. Proc. Inst. Elect. Eng., 125(9): 793-803.

James JR, Henderson A (1978). Investigation of electrically small VHF and HF cavity-type antennas. Proc. Inst. Elect. Eng. Conf. Antennas Propagation, pp. 322-326.

James JR, Vardaxoglou JC (2002). Investigation of properties of electrically small spherical antennas. Electron. Lett., 38(20):1160-1162.

Jensen MA, Rahmat-samii Y (1995). EM Interaction of Handset Antennas and a Human in Personal Communications. IEEE.Proc., 83: 7-17.

Khalabatri S, Sardari D, Mirzaee AA, Sadafi HA (2006). Calculating SAR in two models of the human head exposed to mobile phones radiation at 900 and 1800 MHz. Prog. Electromagn. Res. Symp., pp. 104-109.

Kitra MI, McEvoy P, Vardaxoglou JC, James JR (2003). A theoretical and simulation study of dielectrically loaded `antennas and their contribution towards low SAR. Proc. ITG Conf. on Antennas (INICA), pp. 245-248.

Kim KW, Rahmat-Samii Y (1998). Antennas and human in personal communications: Applications of modern EM computational techniques. 12th International Conference on Microwaves and Radar, May, 4: 36-55.

Kouveliotis NK, Pabagiotou SC, Varlamos PK, Capsalis CN (2006). Theoretical approach of the interaction between a human headmodel and a mobile handset helical antenna using numerical methods. Prog. Electromagn. Res., 65: 309-327.

Krogerus J, Icheln C, Vainikainen P (2005). Dependence of mean effective gain of mobile terminal antennas on side of head. Proceedings of the 35th European Microwave Conference, Paris, France, pp. 467-470.

Meier K, Hombach V, Kastle R, Yew-Siow TR, Kuster N (1997). The dependence of electromagnetic energy absorption upon human head modeling at 1800 MHz. IEEE Trans. Microwave. Theory Tech., 45(11): 2058-2062.

Misran N, Faruque MRI, Islam MT, Abedin HZ (2011). Investigation of Dosimetry in Human Head Model for a Helical Antenna with Mobile Phone. Int. J. Phys. Sci., 6(5): 1000-1008.

Okoniewski M, Stuchly MA (1996). A Study of the Handset Antenna and Human Body Interaction. IEEE Trans. Microwave Theory Tech., 44 (10): 1855-1864.

Sulonen K, Vainikainen P (2003). Performance of mobile phone antennas including effect of environment using two methods. IEEE Trans. Instrum. Measure., 52(6): 1859-1864.

Vardaxoglou JC, James JR, McEvoy P (2003). Creating the definitive low SAR mobile antenna. Institute of Physics Conf. on RF Interactions with Humans: Mechanisms, Exposure and Medical Applications, London, U.K., pp. 245-248.

Wang J, Fujiwara O, Watanabe S (2006). Approximation of aging effect on dielectric tissue properties for SAR assessment of mobile telephones. IEEE Trans. Electromagn. Compatibility, 48(2): 408-413.

Wong KL (2003). Planar Antennas for Wireless Communications. United States of America: A John Wiley & Sons. pp. 529-532.

Wong Z, Chiau CC, Chen X, Collins BS, Kingsley SP, Puccey SC, Thorpe JR (2005). Study and optimisation of a broadband dielectric antenna. In the Conference Proceeding. IWAT'05, Singapore, pp. 125-128.