Karbala International Journal of Modern Science

Volume 7 | Issue 2 Article 8

Graphene as a Shielding Material for SAR Reduction in Human Head using Rectangular and Circular Patch Antenna

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Recommended Citation

Singla, Alka Er.; Marwaha, Anupma Dr.; and Marwaha, Sanjay Dr. (2021) "Graphene as a Shielding Material for SAR Reduction in Human Head using Rectangular and Circular Patch Antenna," *Karbala International Journal of Modern Science*: Vol. 7 : Iss. 2 , Article 8.
Available at: https://doi.org/10.33640/2405-609X.2997

Graphene as a Shielding Material for SAR Reduction in Human Head using Rectangular and Circular Patch Antenna

Abstract

Nanomaterials pave the way for better performance in wireless applications due to their unique properties. Nowadays, these have been used as shield material in dipole antennas for a solution of reduction in SAR value. This work proposes the use of emerging graphene nanomaterial by comparing the performance for two different shapes of patch antenna namely rectangular and circular patch. With the growth in technology, the protection of human health is also mandatory so the work is planned to use graphene as a shielding material for SAR reduction in the human brain and it is proved that for rectangular and circular patch applicators it attains the minimum value of SAR as 0.35 W/Kg and 0.17 W/Kg respectively. Also, antenna parameters using the reconfigurable property of graphene at microwave frequencies are estimated and observed that gain of 8.74 dB and return loss value of -22 dB is achieved for circular patch antenna and gain of 4.28 dB and return loss value of -18 dB is obtained for rectangular patch antenna. The results validate good performance in terms of radiation efficiency and minimum SAR value in comparison to the previously used antennas for shielding purposes.

Keywords

Nanomaterial, Shielding material, Graphene, Circular patch antenna

1. Introduction

The health effects of electromagnetic (EM) radiation due to excessive use of electronic gadgets are a serious concern for the past several years. The radiations emitted from these devices cause biological damage to cells [1] and the heating energy engrossed in the human body is defined as a specific absorption rate (SAR) measured in W/Kg. Limits have been imposed on SAR value by different countries [2]. The standard maximum of 1.6 W/Kg SAR value is a limit imposed according to guidelines issued by Telecom Regulatory of India. So the reduction of SAR value is the prime concern for EM shielding in the recent years of research than performance. In paper [3] materials having in-between conductivity of conductors and insulators such as leather and germanium are proposed for shielding purposes. The shielding material suggested in this work can be used as flip covers for mobile shields. The use of aluminium as shield material proposed in Ref. [4] shows a SAR reduction of 20% considering different phone models. Copper as a shielding material is also used extensively in previous research. Plastic and double-layer silicon sheet for PIFA antennas proposed in Ref. [5] help in reducing SAR by enhancing the performance of an antenna. A tri-band structure of antenna is presented in paper [6] for obtaining low absorption rate using ferrites as shielding materials. Simulations have been performed with a specific position of the antenna with the head. Flexible polymeric ferrite sheets for SAR measurements in planar wearable antennas based on their shielding characteristics are presented in Ref. [7]. EM absorbing property of metamaterials having negative permeability helps in designing safe mobile phone equipment, therefore split ring resonators (SRRs) are proposed [8]. The effect of radiations on the human head has also been by varying the holding position of a mobile device is studied in Ref. [9]. An investigation has been done in Ref. [10] with varying distance from 0 to 10 mm for microstrip patch antenna and analyzed that SAR value and rise in temperature value reduced for larger distances between the human head and mobile phones.

Currently, a study has been published for using nanomaterials as a shielding material that helps in reducing SAR without compromising the performance of the antenna. S. Jemima et al. [11] in their work investigates the performance of carbon-based nanomaterial (CNT) dipole antennas and paves the technique for using nanomaterial as a shielding material to the solution of SAR reduction. Carbon-based nanomaterials including single-wall carbon nanotube (SWCNT), multi-wall carbon nanotube (MWCNT), graphene and its composites such as magneto dielectric composites (MDNC) and reduced graphene oxide (rGO-5, rGO-10) as a shielding material with a dipole radiating element has also been proposed in Ref. [12]. In our previous work [13], efforts have been made for reducing SAR by varying the shape of the antenna. The performance had been evaluated for both rectangular and circular patch antenna and it was concluded that SAR reduction is invariably more in the case of the circular patch antenna. However to further enhance the performance of an antenna and reduction in SAR a proper shielding material is required. For attaining proper EMI protection, highly conductive materials are required for reflecting the EM waves whereas magnetic materials are required for absorbing EM waves. The previously reported work used materials such as copper, nickel, aluminium, silicon sheet and ferrite materials for providing EMI shielding. These materials are however having certain drawbacks such as high density, low flexibility, weak mechanical strength and reflection. In recent years, carbon based nanocomposites have been widely explored for shielding purposes which offer super high electrical conductivity, flexibility, high mechanical strength and prevention from multiple refection mechanisms [14,15]. Thus nanomaterials are pioneers in modern research.

The patch antennas help to obtain a low value of SAR as compared to dipole and helical antennas [16]. Graphene as a patch applicator performs better due to its reconfigurable property and hence acts as radiating element [17]. It also proves to be the best shielding material [11]. Based on the above analysis, this work is focused on the use of graphene nanomaterial as a shielding material for both rectangular and circular patch antenna designs to reduce SAR and rise of temperature in the human brain.

In this paper, a human head model is placed in close proximity to the graphene based rectangular and circular patch antennas at the frequency of 900 MHz to evaluate SAR value and temperature distribution. To evaluate the performance of graphene based patch antennas radiation characteristics, polar plot gain and return loss values are also evaluated.

https://doi.org/10.33640/2405-609X.2997

2. Modelling of graphene patch antenna

2.1. Graphene nanomaterial properties

For designing antennas with appropriate dimensions for better radiation efficiency and improved shielding effects, alternative methods are required for shielding. With the advent of nanomaterials like carbon nanotubes, graphene and its oxides new possibilities have been introduced in the area of antenna design for wireless application. Graphene among all the nanomaterials exhibits astonishing electrical, mechanical, thermal, and chemical properties. It is already proved to be the best conductor at THz range for efficiently radiating the EM waves [18]. The use of graphene at microwave frequencies is still not remarkable. However, due to the advantage of using the CVD method to deposit material into a substrate, applications of graphene in the microwave regime are in infancy [19]. Also the reconfigurable property of graphene for getting electronic tunable conductivity and hence its ability to tune the surface impedance by applying a DC voltage bias making it attractive for utilization in microwave frequencies [20].

The graphene conductivity is given by Kubo's formula as a sum of interband and intraband contribution. However, at microwave frequencies, intraband contribution is mostly dominating [21], whose value is given by:

$$\underbrace{\sigma}_{intraband}(\omega)=\frac{2e^2k_BT}{\pi\hbar^2}ln\left[2cosh\left[\frac{\mu_c}{2k_BT}\right]\right]\frac{j}{\omega+j\tau^{-1}}\cdots \qquad (1)$$

The condition for microwave frequency $\mu_c \gg \hbar\omega$ is required where μ_c is chemical potential and ω is frequency. By defining the values of plank's constant and frequency the condition is generally satisfied at μ_c>>0.05eV. Graphene sheet in this work can be modeled as a surface impedance that depends on the intrinsic conductivity of graphene as given by $Z_s = 1/\sigma(w)$. The surface impedance curve for the real part of conductivity at microwave frequencies is shown in Fig. 1 for different values of chemical potential between 0.25eV and 1eV and it can be seen that the value of surface impedance is 2-4 KΩ at 0.25 eV and the surface impedance for the imaginary part of conductivity is negative as seen in Fig. 2 which can be neglected for further designing. Different values of chemical potential are obtained by varying DC bias voltage which is applied between the PEC ground layer and graphene patch. The DC bias voltage is calculated as described in Ref. [22] that depends on charge carrier density. The graphene conductivity also depends on other parameters such as Boltzmann's constant k_B, reduced Planck's constant $\hbar$ i.e $\hbar = \frac{h}{2\pi}$ and relaxation time $\tau = 10^{-13}$.

For 2-D graphene patch antenna design, the properties of graphene considered for the current analysis are: mass conductivity of graphene is 7200, relative permittivity is 4, conductivity is 10^8(S/m) and the other properties are as listed in Table 1.

Most of the nanomaterials-based shielding materials proposed in previous research are implemented using dipole antennas which however do not provide sufficient gain, directivity, radiation efficiency and return

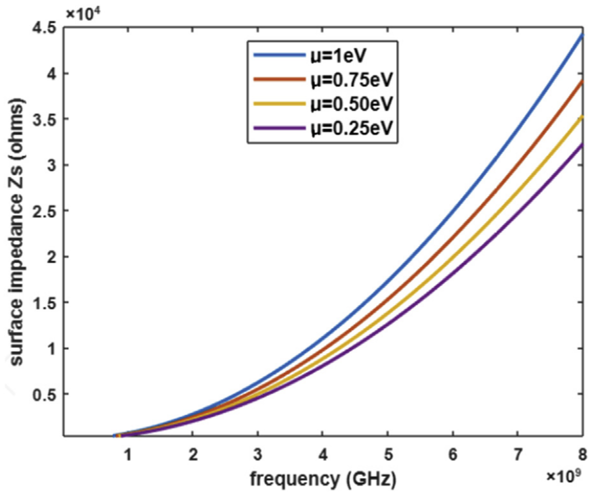


Fig. 1. Surface impedance (real part) of graphene nanomaterial.

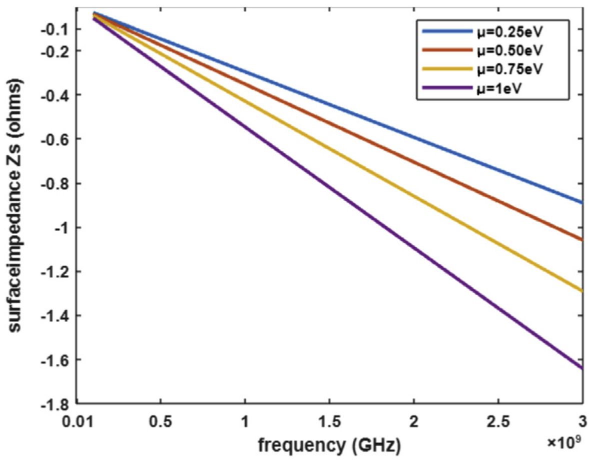


Fig. 2. Surface impedance (imaginary part) of graphene nano material.

Table 1
Properties of graphene [23].

Properties	Graphene Material Parameter values
Conductivity (S/m)	6×10^6
Dielectric Loss Tangent (tan δ_e)	0.077
Heat Capacity (KJ/k/kg)	2100
Thermal Conductivity (W/m-k)	3000−5000
Breaking Strength (N/m)	40
Young's Modulus (TPa)	1
Poisson's Ratio	0.17

loss [11]. Efforts have therefore been done to incorporate graphene nanomaterial based patch antennas for shielding purposes.

2.2. Antenna design

For modeling coupled problem of the human head model with microstrip patch antenna, bioheat transfer module and RF module in COMSOL Multiphysics is used for SAR calculations. The whole problem is simulated using finite mesh element (FEM) analysis which is used to carry out the computational analysis. Graphene is used as a shielding material in this work whose hexagonal tightly packed 2-dimensional structure is a flat monolayer of sp^2 carbon atoms and hence 2-D graphene is considered for acting as a patch radiator placed on a metallic plane known as the ground plane with a dielectric medium in between them. The dimensions are selected in such a way that the patch antenna should resonate at the desired frequency for that length of the patch is taken to be $\lambda_0 / \sqrt{\in_r}$, where λ_0 is wavelength in free space and $\in_r$ is the relative permittivity of the substrate. A material having low permittivity is required for better radiation efficiency [24], so FR4 substrate having a dielectric constant of 4.5 and thickness of 3.5 mm is considered here and a 2-D layer of graphene patch is placed on it. After the selection of a suitable substrate, the other dimensions of the antenna are determined based on the given literature [25]. The geometry of both the proposed applicator designs is shown in Fig. 3 consists of rectangular patch having dimensions 39.2×39.2 mm^2 and a circular patch of radius 32 mm. Perfect electric conductor (PEC) boundary conditions are selected for the ground plane of a substrate and radiating patch. The coupled design of the human head and microstrip patch antenna is surrounded by a perfectly matched layer (PML) for the sake of absorbing outgoing radiations.

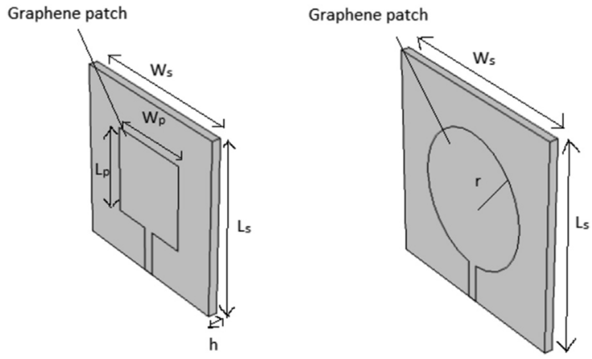


Fig. 3. Rectangular and circular graphene patch antenna.

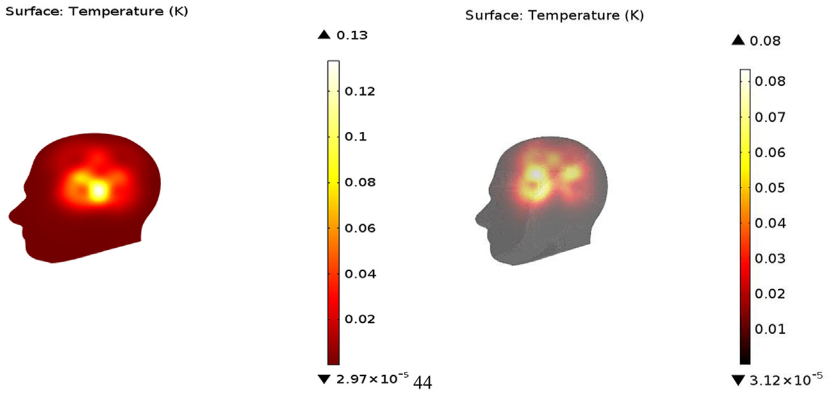
The microstrip feed line is used to provide the feed to the antenna for proper impedance matching of 50 Ω as it is connected directly to the edge of the patch antenna.

Finally based on the properties of graphene, a final computational model of human head interaction with graphene-based rectangular and circular patch applicator has been developed. The human head model was made by a Specific Anthropomorphic Mannequin (SAM) phantom i.e. geometry already in-built in COMSOL Multiphysics software [26]. The dielectric properties of the human head as given in Ref. [27] are considered for direct simulation of results. Performance has been evaluated by placing the graphene antenna at 20 mm distance from the human head. Electromagnetic problem is solved using finite element method (FEM) based analysis as it is more suitable for problems having inhomogeneous configurations [28].

3. Simulation results

The proposed graphene nanomaterial for EM shielding is considered for the current simulation setup. Different simulation results such as radiation efficiency, polar plot graph, return loss value, SAR distribution and temperature distribution plot have been discussed in this section for graphene-based both rectangular and circular antennas. The chemical potential of graphene sheet is adjusted to be at 0.25eV obtained by giving the DC bias potential voltage of 5 V between graphene patch and PEC ground layer that gives the lowest value for the real part of surface impedance as 2−4 KΩ. Fig. 4 plots rise in temperature distribution above normal body temperature for the proposed antennas and it is observed that rise in temperature is 0.13 °C and 0.8 °C for graphene-based both the applicators.

SAR reduction for the proposed nanomaterial has also been investigated. From Fig. 5 for SAR



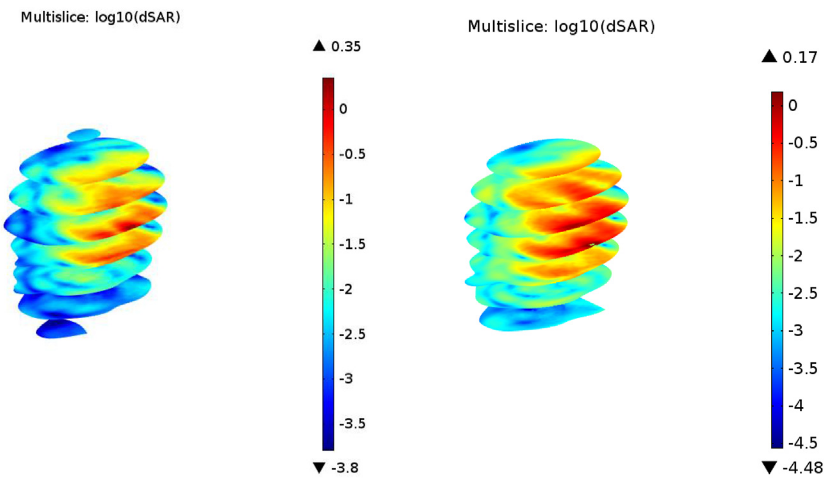
(a) (b)

Fig. 4. Rise in temperature distribution plots (a) rectangular patch antenna and (b) circular patch antenna.

distribution, it is demonstrated that rectangular and circular patch antennas having a maximum of 0.35 W/Kg and 0.17 W/Kg SAR value for 10 g tissue of the human brain. Thus the graphene nanomaterial used in the proposed setup shows a significant SAR reduction of 83% and 65% for circular and rectangular patch antenna designs.

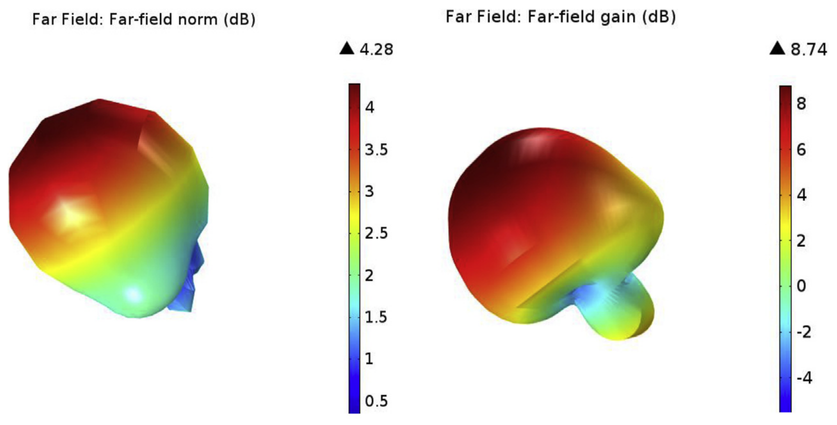
The literature using conventionally used shielding materials [3–7] asserts that there must be a trade-off between antenna performance and SAR reduction factor (SRF). The utilization of carbon-based nanomaterials in shielding applications however authenticate that there is a minimal trade-off requirement [11,12]. Further in order to validate the performance of proposed antenna designs, radiation pattern, polar plot gain and return loss characteristics have also been demonstrated. Fig. 6 shows the radiation pattern of rectangular and circular patch antenna yielding a far-field gain value of 4.5 dB and 8.74 dB respectively (see Table 2).

Polar plot gain for different values of chemical potential i.e. $\mu = 0.25$ eV, 0.50 eV and 0.75 eV have also been calculated. It can be clearly seen from the plot that the maximum gain of 8.74 dB is achieved for the chemical potential value of $\mu = 0.25$ eV. However, the maximum gain of 6.5 dB and 5.5 dB are achieved at $\mu = 0.50$ eV and 0.75 eV which are less than the gain achieved at 0.25 eV. These values are evaluated for circular patch antenna. For rectangular patch antenna maximum gain achieved is 4.7 dB for $\mu = 0.25$ eV, 3.61 dB for $\mu = 0.50$ eV and 2.77 dB for $\mu = 0.75$ eV. Fig. 7 shows the polar plot curves for rectangular and



(a) (b)

Fig. 5. SAR distribution plots (a) rectangular patch antenna and (b) circular patch antenna.



(a) (b)

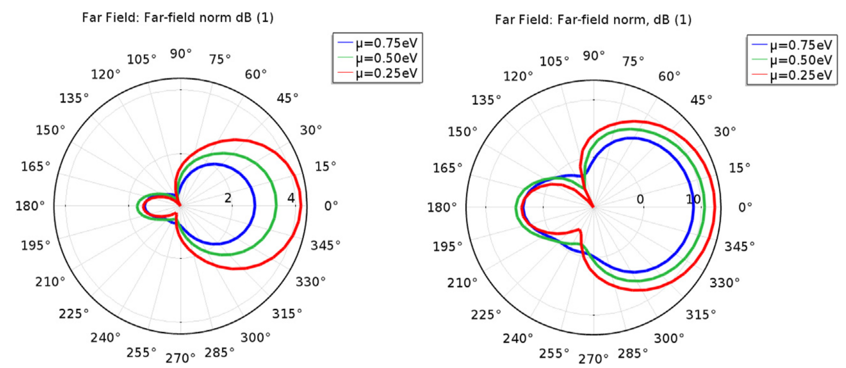
Fig. 6. Radiation pattern (a) rectangular patch antenna and (b) circular patch antenna.

Table 2
Geometry of graphene patch antenna.

Parameter	Dimensions
Length and width of rectangular patch ($L_p \times W_p$)	39.2 × 39.2 mm^2
Radius of circular patch	32 mm
Dielectric constant of substrate (ϵ_r)	4.5
Height of substrate (h)	3.5 mm

circular patch antenna. Moreover, the value of directivity for both the antennas has also been calculated as listed in Table 3.

Another important parameter i.e. a return loss ensuring maximum radiation efficiency at specified resonant frequency has been evaluated as shown in Fig. 8 for rectangular and circular patch antenna at chemical potential of $\mu = 0.25$ eV. The graphene nanomaterial based circular patch antenna attains the maximum return loss value of −22 dB while the graphene based rectangular patch antenna achieves a lower return loss value of −18dB. Due to feed proper impedance matching of 50 Ω, return loss values for both the antennas are observed at desired resonance frequency. To analyze the performance of patch antenna with graphene nanomaterial, the comparison of SRF factor and antenna performance parameters is done which is given in Table 3. Comparison has been made with previous work in which graphene nanomaterial has been used as a shielding material with dipole antennas [11] and it is demonstrated that there is much reduction in SAR value for the proposed design. Though the gain for dipole antenna is comparable to rectangular patch antenna however much-improved gain of 8.74 dB is achieved for nanomaterial-based circular patch antenna. Moreover, the comparison has also been done with simple copper conducting patches



(a) (b)

Fig. 7. Polar plot gain for varying chemical potential (a) rectangular patch antenna (b) circular patch antenna.

Table 3
Performance comparison of antenna designs for SAR reduction.

Antenna Designs	SAR	Rise in temperature	Gain (dB)	Directivity (dB)	Return loss (dB)
Circular graphene patch antenna (Present study)	0.17 W/Kg	0.08 °C	8.74	9	−22 dB
Rectangular graphene patch antenna (Present study)	0.35 W/Kg	0.13 °C	4.28	4.7	−18 dB
Circular copper conducting patch antenna (Previous study) [13]	0.16 W/Kg	0.09 °C	6.4	6.1	−12 dB
Rectangular copper conducting patch antenna (Previous study) [13]	0.32 W/Kg	0.15 °C	3.5	3.2	−11 dB
Graphene based dipole antenna (Previous study) [12]	0.668 W/Kg	–	6	5	–

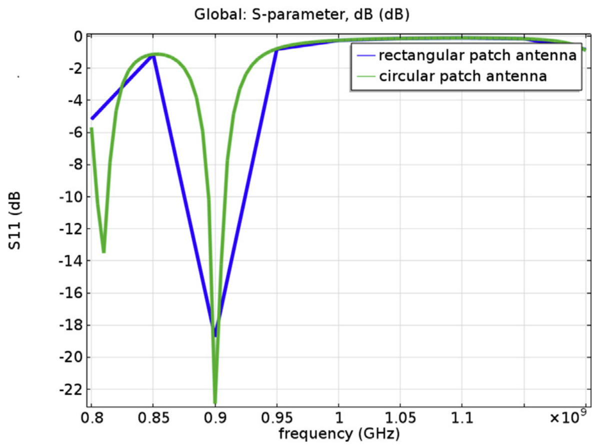


Fig. 8. Return loss characteristics for both shapes of antenna.

of rectangular and circular shapes previously done in Ref. [13]. It is observed that there may not be much difference in SAR value but the performance of the antenna is significantly improved in terms of return loss and radiation characteristics.

Further nanomaterial-based circular patch antenna proves to be more efficient than rectangular patch antenna for shielding purposes. The dipole antenna using graphene nanomaterial shows reasonable gain and SAR within permissible limits but square and circular shapes of patch antenna are more preferable shapes these days for wireless communication applications.

4. Conclusion

This paper proposing a novel approach of using graphene nanomaterial for EM shielding presenting a good solution for SAR reduction with minimum effects on the performance of antenna parameters. All the factors such as SRF reduction, gain directivity and return loss characteristics for both the shapes of circular and rectangular patch antenna have been studied and it has been observed that there are 83% and 65% SRF factor for the two shapes respectively. Also, the gain of nanomaterial-based circular patch antenna is 8.74 dB which is much better than the gain of 4.28 dB for rectangular patch antenna at the chemical potential of $\mu = 0.25$ eV. It has also been investigated that the re-configurability property of graphene to tune the intrinsic conductivity yields surface impedance of 2−4 KΩ at microwave frequencies which helps in improving the antenna gain parameters with minimum side effects. Our future work will focus on the investigation of other nanomaterials for solving the SAR issue and achieving better antenna performance.

Declaration of competing interest

No conflict of interest among authors.

Acknowledgements

This work is supported by DST FIST-2018 project (reference no. SR/ET-I/2018/157).

References

[1] A.B. Rifai, M.A. Hakami, Health Hazards of electromagnetic radiation, J Biosci Med 2 (8) (2014) 1−12, https://doi.org/10.4236/jbm.2014.28001.
[2] M. Yang, W. Guo, C. Yang, J. Tang, Q. Huang, S. Feng, et al., Mobile phone use and glioma risk: a systematic review and meta-analysis, PLoS One 12 (5) (2017), e0175136.
[3] P.K. Dutta, P.V.Y. Jayasree, V.S.S.N.S. Baba, SAR reduction in the modelled human head for the mobile phone using different material shields, Human-centric Comput Info Sci 6 (1) (2016).
[4] K.H. Chan, K.M. Chow, L.C. Fung, S.W. Leung, Effects of using conductive materials for SAR reduction in mobile phones, Microw Opt Technol Lett 44 (2) (2005) 140−144, https://doi.org/10.1002/mop.20569.
[5] M.I. Hossain, M. Faruque, M.T. Islam, A new design of cell phone body for the SAR reduction in the human head, ACES J 30 (7) (2015).
[6] M.I. Kitra, C.J. Panagamuwa, P. McEvoy, J.C. Vardaxoglou, J.R. James, Low SAR ferrite handset antenna design, IEEE Trans Antenn Propag 55 (4) (2007) 1155−1164, https://doi.org/10.1109/tap.2007.893370.
[7] R. Augustine, T. Alves, T. Sarrebourse, B. Poussot, K.T. Mathew, J.M. Laheurte, Polymeric ferrite sheets for SAR

reduction of wearable antennas, Electron Lett 46 (3) (2010), https://doi.org/10.1049/el.2010.3246, 197−197.
[8] M.B. Manapati, R.S. Kshetrimayum, SAR reduction in human head from mobile phone radiation using single negative metamaterials, J Electromagn Waves Appl 23 (10) (2009) 1385−1395, https://doi.org/10.1163/156939309789108606.
[9] M.R. Iqbal-Faruque, N. Aisyah-Husni, M. Ikbal-Hossain, M. Tariqul-Islam, N. Misran, Effects of mobile phone radiation onto human head with variation of holding cheek and tilt positions, J Appl Res Technol 12 (5) (2014) 871−876, https://doi.org/10.1016/s1665-6423(14)70593-0.
[10] S.I. Zonoori, S.V.A.D. Makki, A. Torabi, A Comparative study of the distance effects of human head from mobile phone radiation, Int J Microwave Opt Technol 10 (1) (2015) 20−27.
[11] S.J. Priyadarshini, D.J. Hemanth, Investigation of nanomaterial dipoles for SAR reduction in human head, Frequenz 73 (5−6) (2019) 189−201, https://doi.org/10.1515/freq-2018-0220.
[12] J.P. Stephen, D.J. Hemanth, An investigation on specific absorption rate reduction materials with human tissue cube for biomedical applications, Int J RF Microw Computer-Aided Eng 29 (12) (2019), https://doi.org/10.1002/mmce.21960, 21960−21960.
[13] A. Singla, A. Marwaha, S. Marwaha, Reduction of specific absorption rate (SAR) for human head using circular patch antenna, 7th International Conference on Signal Processing and Integrated Networks (SPIN), 2020, pp. 189−192.
[14] F.M. Oliveira, R. Gusmao, Recent advances in the electromagnetic interference shielding of 2D materials beyond graphene, ACS Appl Electr Mater 2 (10) (2020) 3048−3071.
[15] P. Kumar, Ultrathin 2D nanomaterials for electromagnetic interference shielding, Adv Mater Inter 6 (24) (2019) 1901454.
[16] M.I. Hossain, M.R.I. Faruque, M.T. Islam, Low SAR microstrip patch antenna for mobile phone, Frequenz 69 (9−10) (2015) 399−405.
[17] J. Perruisseau-Carrier, M. Tamagnone, J.S. Gomez-Diaz, E. Carrasco, Graphene antennas: can integration and reconfigurability compensate for the loss?, in: European Microwave Conference IEEE, 2013, pp. 369−372.
[18] R. Bala, A. Marwaha, Characterization of graphene for performance enhancement of patch antenna in THz region, Optik 127 (4) (2016) 2089−2093, https://doi.org/10.1016/j.ijleo.2015.11.029.
[19] Jesus de La Fuente, CVD graphene − creating graphene via chemical vapour deposition, Graphenea, 2015.
[20] C.N. Alvarez, R. Cheungy, J.S. Thompson, Graphene reconfigurable antennas for LTE and WIFI systems, 2014 Loughborough antennas and propagation conference, LAPC, 2014, pp. 434−438.
[21] M. Bozzi, L. Pierantoni, S. Bellucci, Applications of graphene at microwave frequencies, Radioengineering 24 (3) (2015) 661−669, https://doi.org/10.13164/re.2015.0661.
[22] R. Bala, A. Marwaha, Development of computational model for tunable characteristics of graphene based triangular patch antenna in THz regime, J Comput Electron 15 (1) (2016) 222−227, https://doi.org/10.1007/s10825-015-0761-6.
[23] S. Dhariwal, V.K. Lamba, A. Kumar, Simulation and performance analysis of carbon nano-materials based patch antennas, Indian J Sci Technol 9 (4) (2016) 1−8, https://doi.org/10.17485/ijst/2016/v9i4/84748.
[24] S.Z. Sajal, B.D. Braaten, V.R. Marinov, A microstrip patch antenna manufactured with flexible graphene-based conducting material, in: 2015 IEEE international symposium on antennas and propagation & USNC/URSI National Radio Science meeting, 2015, pp. 2415−2416.
[25] B.J. Kwaha, O.N. Inyang, Amalu, The circular microstrip patch antenna- design and implementation, Int J Res Rev Appl Sci (8) (2011) 86−95.
[26] B.B. Beard, W. Kainz, T. Onishi, T. Iyama, S. Watanabe, O. Fujiwara, et al., Comparisons of computed mobile phone induced SAR in the SAM phantom to that in anatomically correct models of the human head, IEEE Trans Electromagn C 48 (2) (2006) 397−407.
[27] S. Gabriel, R.W. Lau, C. Gabriel, The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues, Phys Med Biol 41 (11) (1996) 2271−2293, https://doi.org/10.1088/0031-9155/41/11/003.
[28] G. Belingardi, G. Chiandussi, I. Gaviglio, Development and validation of a new finite element model of human head, 19th International Technical Conference of the Enhanced Safety of Vehicle, ESV, vol. 35, 2005.