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Mathematical analysis of a metamaterial structure for Electromagnetic (EM) absorption reduction

Tanveer Ahsan
Department of Computer Science and Engineering
International Islamic University Chittagong (IIUC), Bangladesh

Abstract
The rapid development of communication system such as the second generation (2G) and third-generation (3G) mobile communications, global position system (GPS), WiFi, WiMAX, wireless Bluetooth and Ultra-Wideband (UWB) systems have driven the wireless technology to a revolutionary communications. Besides, high data rate communication system has led to great demand in higher frequency next generation communication system. The wireless devices emit electromagnetic (EM) radiation during active mode of operation which is absorbed by human body. The main challenge of the next generation communication system is to ensure safe use of wireless devices such as mobile phone. Therefore, EM radiation should be controlled towards human body. In this research, a metamaterial structure is developed and the performances of the structure is analyzed. The structure consists of a modified omega-shaped split resonator which can manipulate the behaviour of the EM wave. The mathematical analysis of the proposed antenna shows 63.29% point EM radiation reduction.

Keywords EM absorption, Metamaterial, Next generation communication, Wireless devices

Paper type Research paper

1. Introduction

During last few decades, communication system has explored with various advance technologies to benefit and enlighten the human life. With the invention of telephone, a revolutionary change was observed in human civilization. Later, the communication technology offered radio technology, by which a whole new level of communication system was introduced such as cellular and satellite networks. Multifunctional smart communication system has led the demand of high data rate multiband communication technology (Hakim, Alam, Baharuddin, & Islam, 2022). The higher 5G band wireless technology could be the best choice to fulfil the stringent demands of the new generations (Hakim, Uddin, & Hoque, 2020).

The wireless devices emit electromagnetic (EM) radiation during active mode of operation. The human body

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absorbed the radiated EM waves up to a certain level. There are many short and long-term effects of EM radiation on human health. The active source of this radiation is the integrated antenna with the device. There are several myths about the biological effect for using a mobile phone. Tissue heating is one of them. The principal mechanism of tissue heating is the interaction between radio frequency energy and the human body. When the mobile phone is used, most of the energy is absorbed by the skin and other superficial tissues that might increase the temperature of biological tissues (Bernardi, Cavagnaro, Pisa, & Piuzzi, 2000; Tahvanainen et al., 2007; Yan, Agresti, Bruce, Yan, Granlund, & Matloub, 2007). The research is still ongoing. The effects of radio frequency fields on brain have been investigated (Auvinen, Hietanen, Luukkonen, & Koskela, 2002; Inskip et al., 2001; Muscat et al., 2000; Schüz, Jacobsen, Olsen, Boice, McLaughlin, & Johansen, 2006). Extensive use of mobile phone have high risk on brain (Ahlbom et al., 2009; Schüz, Jacobsen, Olsen, Boice, McLaughlin, & Johansen, 2006). It had been ruled out that by more than 50% of the RF energy emitted from mobile phone being absorbed at the side hemisphere of the brain where the mobile phone is usually held to (Cardis et al., 2008). The side of the brain (temporal lobe) absorbed the highest RF energy. This side of the brain always recorded the highest RF absorption. However, this absorption was recorded for long term usage of mobile phone. Similarly, the short-term usage of mobile phone could lead to such phenomenon. Some studies had found that there is a rising risk on human body with cardiac arrhythmia and acute myocardial infarction due to EM radiation (Swerdlow, Feychting, Green, Kheifets, & Savitz, 2011).

There are some established methods for EM reduction, metamaterial is one of them (Hakim, Alam, Almutairi, Mansor, & Islam, 2021; Hakim, Alam, Sahar, Misran, & Mansor, 2021; Hwang & Chen, 2006; Islam, Faruque, & Misran, 2010, 2011; Manapati & Kshetrimayum, 2009). In (Hwang & Chen, 2006) proposed SRRs metamaterial structure to reduce SAR of the mobile phone. In (Manapati & Kshetrimayum, 2009), 57% of the SAR reduction has been achieved using open split ring resonators (OSRRs). By using split ring resonators (SRRS) array, 42.12% of SAR reduction was obtained in (Islam et al., 2010). After that, SRR based metamaterial achieved 63.40% of the SAR value reduction in (Faruque, Misran, & Islam, 2011). In sequence (Faruque, Islam, & Ali, 2013) developed SMMs metamaterial for electromagnetic absorption reduction, where 53.06% of EM reduction was achieved.

The motivation focused on this research is to ensure safer use of mobile phones by designing and developing a new metamaterial to control EM radiation. The performances are comprehensively investigated in the presence of a three-layered human phantom.

2. Methodology

The initial design of the proposed metamaterial has been designed using commercially available CST electromagnetic simulator software. The simulation setup of the metamaterial unit cell has been described in (Hakim, Alam, Islam, Baharuddin, et al., 2022; Hakim, Alam, Sahar, Misran, & Mansor, 2021; Musa et al., 2022). Figure 1 illustrates the design of the proposed metamaterial with design parameters. Figure 2 shows the EM simulation setup with three layered human phantom and 28GHz antenna. The phantom consists of three layers: skin, muscle and bone. The material properties have been considered as bio tissue model of CST studio software. Moreover, the antenna has been customized using Antenna Magus. The antenna operates from 27.735 GHz to 33.5 GHz with 90% total efficiency at 28 GHz.

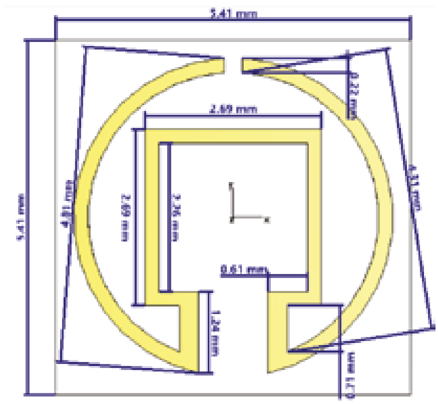


Figure 1
Geometric layout of the metamaterial

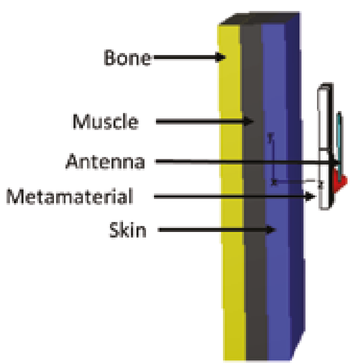


Figure 2
EM absorption analysis setup

3. Result analysis

The scattering parameters of the proposed metamaterial has been presented in Figure 3. The S11 and S22 presents the reflection coefficient of the port in the front side and back side of the metamaterial. On the other hand, S21 and S12 present the transmission coefficient among the port. The transmission bandwidth shows a complete blocking of the wave through the metamaterial at 28 GHz frequency band. The relative parameters of the metamaterial have been described in (Hakim, Alam, Baharuddin, & Islam, 2022; Hakim, Alam, Islam, Salaheldeen, et al. 2022; Hakim, Hanif, et al., 2022; Musa, Hakim, Alam, Baharuddin, & Singh, 2021). The metamaterial property has been presented in Figure 4(a-b). The negative value of both permittivity and permeability makes proposed metamaterial as double negative (DNG) metamaterial which acts as backward wave propagations (Hakim, Alam, Soliman, et al., 2022). The features are also understood from negative reflective index and reflected wave plot in Figure 4c and Figure 4d, respectively. Moreover, E-field, h-field and surface current distribution at 28 GHz have been investigated and presented in Figure 5. All results show that the structure responded well at 28 GHz and match well with the results in Figure 4.

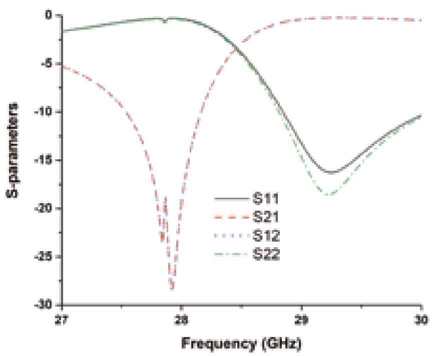
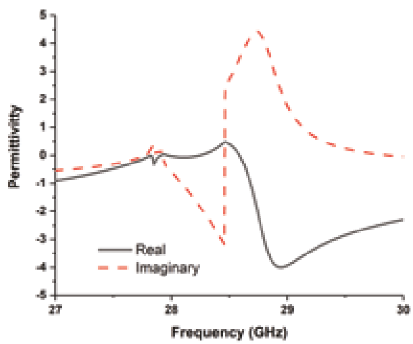
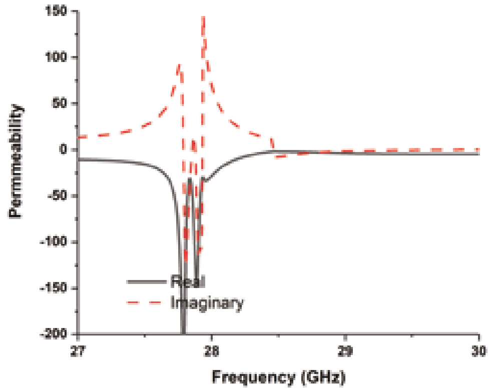


Figure 3

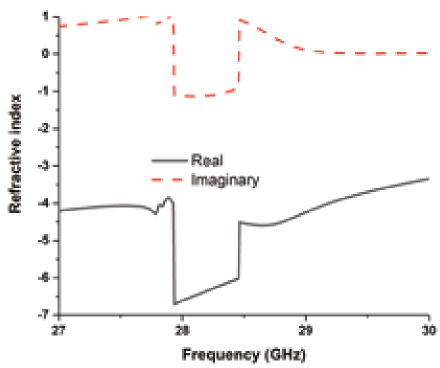
Scattering parameters of the proposed structure



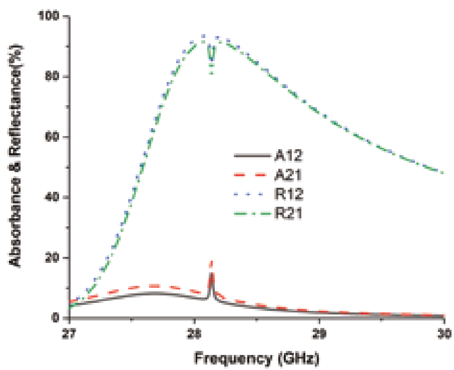
(a)



(b)



(c)



(d)

Figure 4
(a)Relative permittivity, (b) permeability, (c) effective refractive index; and (d) absorbance and reflectance of the proposed metamaterial.

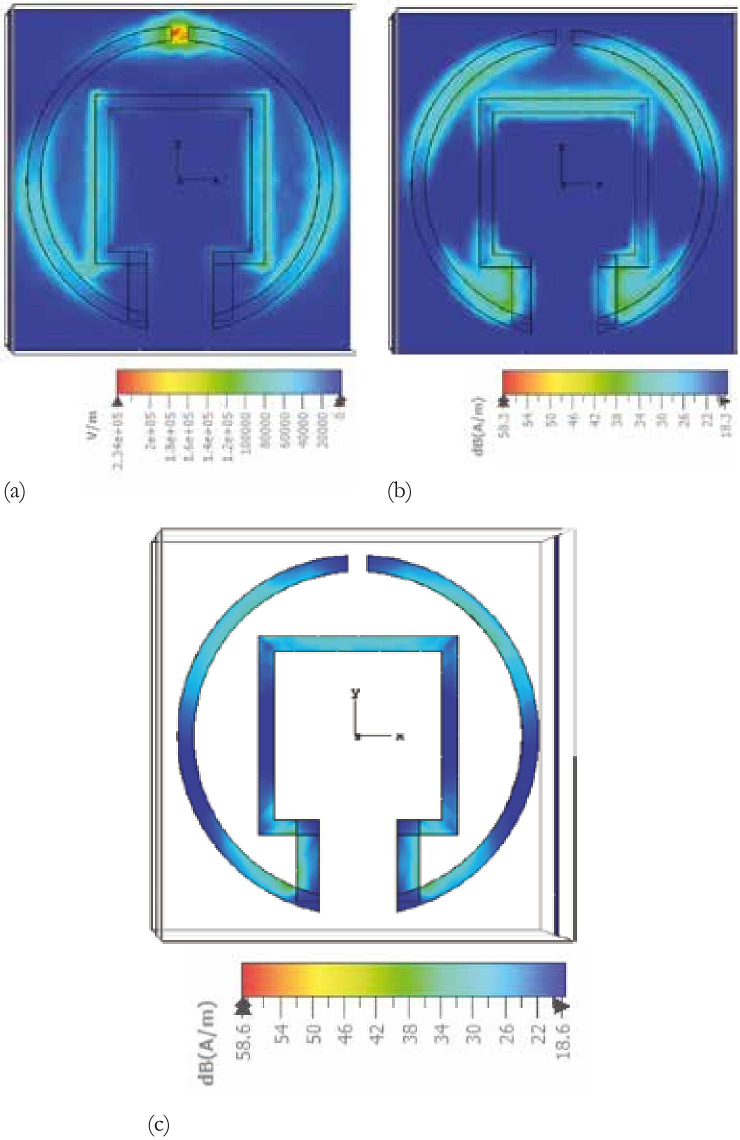
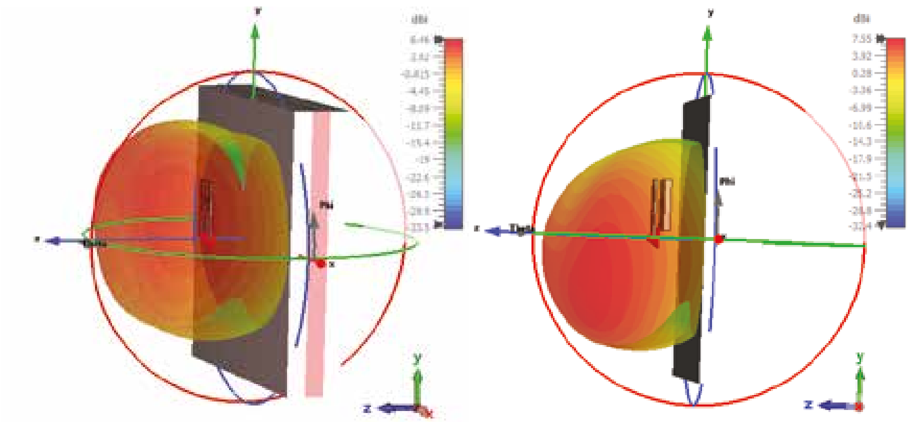


Figure 5
(a)E-field, (b) h-field and (c) surface current distribution of the proposed metamaterial

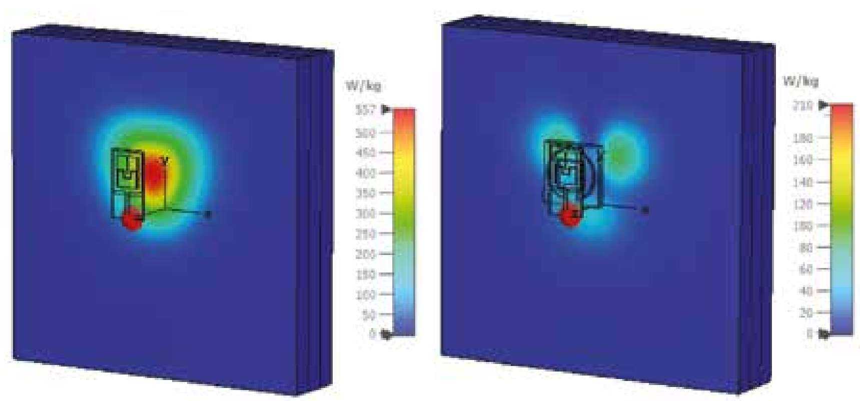
The EM absorption reduction has been investigated with 3-layered human phantom. Firstly, the antenna performances have been investigated without metamaterial attachment. After that the performances have been analyzed with metamaterial structure attachment behind antenna structure. 3D radiation pattern with and without metamaterial is illustrated in Figure 6. It is shown that the antenna directivity increased after metamaterial integration which focuses EM wave reflection and shield to propagate towards human phantom.



(a) (b)

Figure 6
(a) 3D radiation pattern without metamaterial and (b) 3D radiation pattern with metamaterial

Figures 7(a) and 7(b) depicted the simulated point SAR values without and with metamaterial attachment respectively. It is observed from Figure 7 that the SAR value is reduced by 62.29% after metamaterial structure integration, which shows the intensity of EM wave absorption reduction.



(a) (b)

Figure 7
(a) point SAR without metamaterial and (b) point SAR with metamaterial

4. Conclusion

The paper presents development and analysis of a metamaterial structure for EM absorption reduction, which can operate 28 GHz 5G standards. The metamaterial structure satisfies the EM absorption guidelines established by IEEE and International Commission on Non-Ionizing Radiation Protection (ICNIRP) without degrading antenna performances at upper 5G band. EM absorption reduction by 62.29% makes the structure a potential candidate for safer 5G communication system.

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Corresponding author
Tanveer Ahsan can be contacted at: tanveer.ahsan@gmail.com